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A Renovation Decision-Support Model for Evaluating the Functional Condition of Army Facilities

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Building renovation is an important alternative to consider in the Army real-property master planning process. Renovation may or may not be cost-effective or feasible, depending on the facility's condition and its ability to fulfill its intended mission. Some quantitative approaches exist for measuring the potential value of a building investment, but qualitative factors generally weigh more heavily in investment decisions. While some qualitative benefits can be quantified in terms of cost, most (e.g., convenience) do not lend themselves to quantification in any practical way.

This research has produced a comprehensive set of functional condition attributes, rating scales, and a method for weighting the attributes. These elements have been integrated into a renovation decision-support model called RENMOD, designed to help Army facility managers more objectively measure the functionality of a facility for a new mission. RENMOD has been automated in a prototype microcomputer application.

Special professional expertise (e.g., registration as an architect or engineer) is not required for assessment of most functional condition attributes, but familiarity with Army regulations, standard design features, and design guides will enhance decisions an inspector makes using RENMOD.

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FOREWORD

This research was conducted for the Assistant Chief of Staff for Installation Management (ACSIM) under Project 4A162784AT41, "Military Facilities Engineering Technology"; Work Unit FH-AE3, "Facility Renewal Decision Support Model." The technical monitor is Stan Shelton, DAIM-FDP-P.

The work was performed by the Facility Management Division (FF) of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). Alan W. Moore is Acting Chief, CECER-FF, and Dr. Michael J. O'Connor is Chief, CECER-FL. The USACERL technical editor was Gordon L. Cohen, Information Management Office.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

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A RENOVATION DECISION-SUPPORT MODEL FOR EVALUATING THE FUNCTIONAL CONDITION OF ARMY FACILITIES

1 INTRODUCTION

Background

A large percentage of the nation's resources is used in the construction and maintenance of facilities. Most facilities, if properly constructed and maintained, have a long physical life. Frequently, a building will outlive its original purpose, so the owner must choose whether to sell, demolish, or reuse the building for a new purpose. Renovating a building, whether to continue serving its original purpose or to meet a new need, is costly. The building owner must weigh renovation decisions carefully to be sure renovation is appropriate and cost-effective.

The U.S. Army, as the owner of a large building inventory, must continuously decide whether to renovate buildings. Master planners at Army installations plan for future occupancy needs by analyzing facility requirements and developing a strategy to satisfy those requirements. One objective of real property master planning is to determine real property deficiencies and identify the most economic alternative to eliminate that deficiency (Army Regulation [AR] 210-20).

The process of deciding whether to renovate a building is not necessarily straightforward. What criteria are used in the evaluation? How is the value of a building truly measured? These are two examples of the issues decisionmakers must consider. While there are established quantitative approaches for measuring the economic value of building investments, there are always qualitative factors that have (or should have) a major impact on the renovation decision. The functionality of buildings affects productivity. Even a minor productivity gain or loss can have major cost consequences. A realistic assessment of a facility's capabilities of satisfying its functional requirements must be made as part of any renovation decision.

The renovation decision depends on the physical, functional attributes of the building, and the financial consequences of the renovation. The questions that an evaluation must answer are:

1. Is the facility functionally adequate to satisfy the mission requirements?

2. Is renovation the best way to satisfy the requirement?

The only type of information generally available to the decisionmaker is cost data, which is quantitative. However, the suitability of the facility to its intended use, the efficiency of the building plan, and aesthetics are also important in determining a building's value—and these are qualitative factors for which no data may exist. Both qualitative and quantitative factors must be included in a renovation analysis. The U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked to develop a decisionmaking method that includes both qualitative and quantitative information to support more effective renovation decisions.

Objective

The objective of this work was to develop a model and a methodology for more objective evaluation of a facility's functional adequacy, to enhance an installation planner's ability to make effective building renovation decisions.

Approach

A search was conducted of building economics literature, U.S. Army Corps of Engineers (USACE) design guides, Army project development brochures, and sources of multiattribute decision analysis theory. The information was used to develop an initial model of facility renovation decisionmaking. The robustness of the initial model was tested using the Monte Carlo simulation method.

Next, three weighting methods were assessed for application to the decision criteria. The methods were tested by a "knowledgeable individual"—not the decisionmaker but a person qualified to inspect facilities and consider renovation planning issues—to determine which would be most effective for carrying the relative importance of each evaluative criterion through the model and into an effective renovation decision. Six planners from different Army installations also assessed the weighting methods. The method that enabled the model to render the most valid renovation decision, in the opinion of the seven evalutators, was chosen for incorporation into the model.

Experts in the field then participated in a workshop at USACERL to validate the basic structure of the model, refine details and descriptions of the attributes, and validate the weighting method.

Finally, the refined model—called RENMOD—was implemented as an application for desktop microcomputers.

This report documents both the development of RENMOD and presents the final results of the work. Figure 1 shows the original building attribute tree structure that was the basis for simulation and expert critique. Figure 2 shows the revised attribute tree for RENMOD.

Mode of Technology Transfer

The work reported here will feed into research conducted under Work Unit FH-AZ3, "Real Property Planning, Acquisition, and Disposal." The findings of this study will also be shared with the Office of the Assistant Secretary of the Army–Financial Management for possible incorporation into the Installation Status Report, a facilities management tool now being developed under the direction of that office.

The prototype computer implementation of RENMOD is available from the USACERL Installation Planning Team (CECER-FFM), telephone 1-800-872-2375. The software requires Microsoft Disk Operating System version 5.0 or later, 640 kilobytes of random access memory, and at least 2 megabytes of free space on the hard disk.

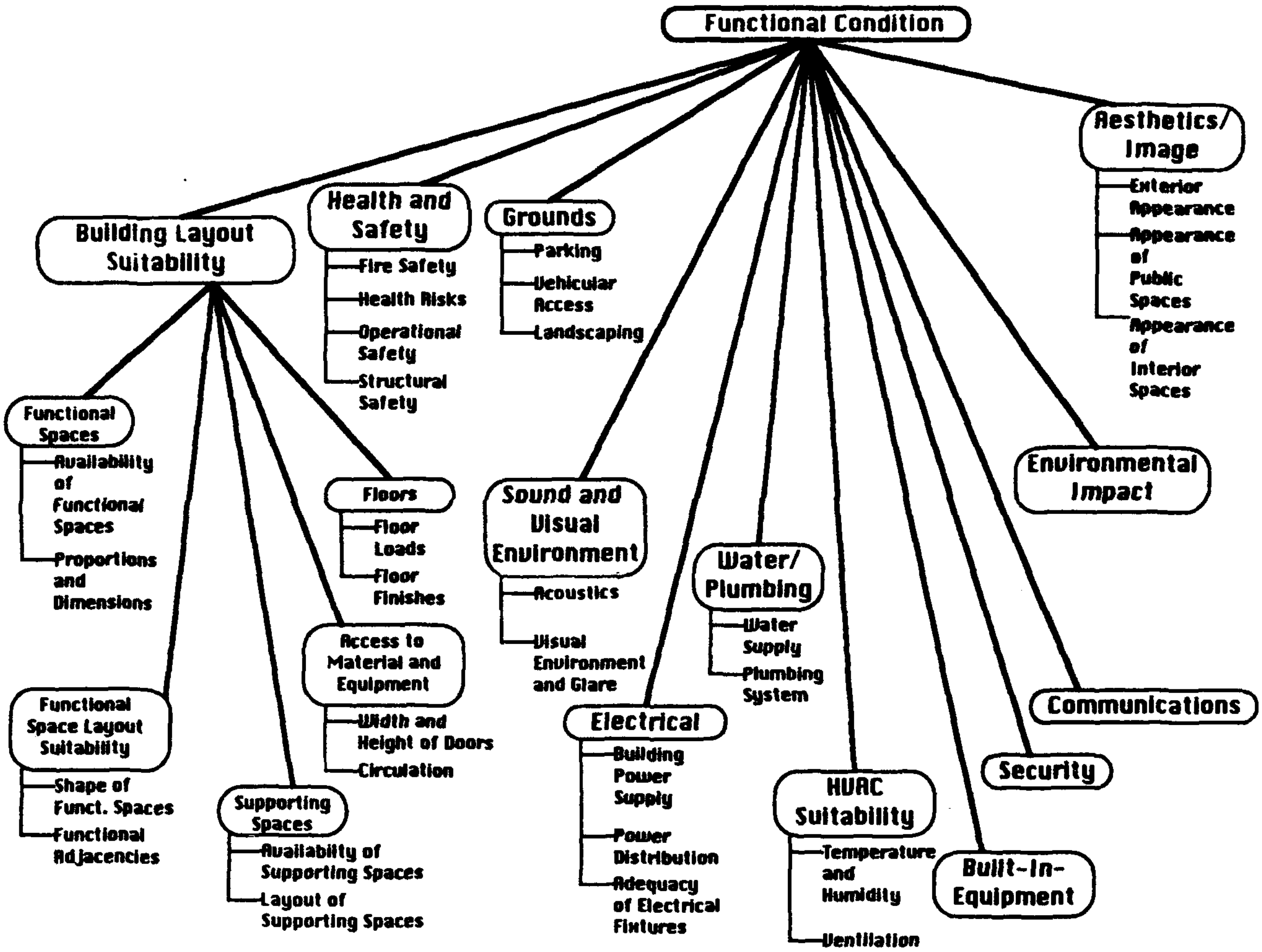

Figure 1. Original Building Attribute Tree Structure.

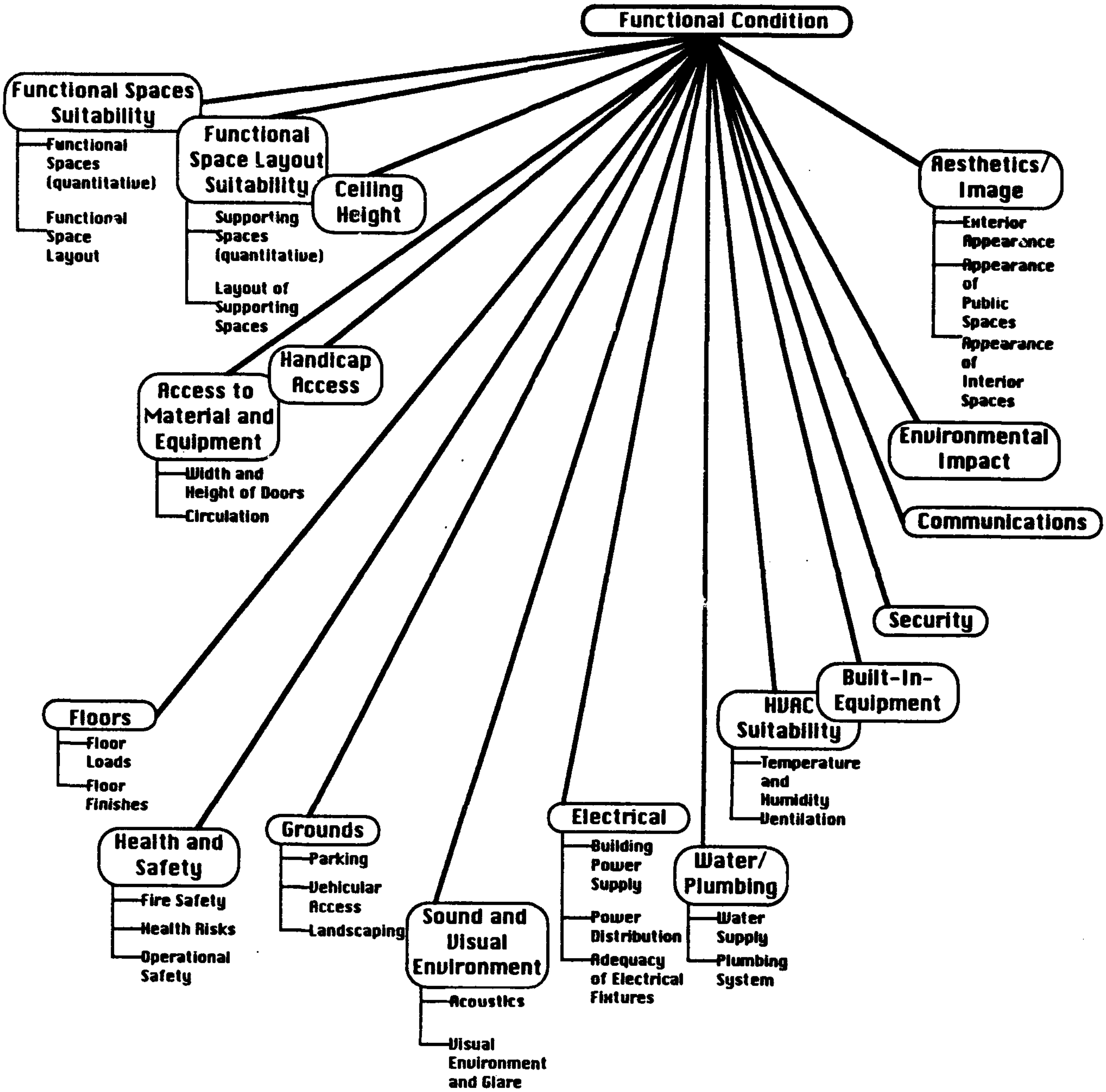

Figure 2. Revised Attribute Tree Structure for RENMOD.

2 BUILDING RENOVATION DECISIONS

Renovation Problem Definition

The term renovation means different things to different people. To a homeowner, it means any home improvement. To an economist, it is any investment designed to forestall the capital depreciation of a structure. To an architect, it is redesign of the facility. To a facility planner and manager, it is any facility improvement that satisfies occupancy needs and allows that facility to return to a state of usefulness. Presuming that a facility was originally useful, renovation restores it to acceptable levels of functional and technical performance. The focus of this research is on the evaluation of renovation projects from the perspective of a facility planner and manager.

Renovation restores a facility to acceptable levels of functional and technical performance. It may require the rebuilding of a facility, modernization, restoration, or making major improvements to a facility to avoid the consequences of physical and technological obsolescence. Ordinary maintenance and repair (M&R) activities prevent deterioration of a facility, whereas renovation improves it.

Renovation is sometimes combined with other activities, such as conversion or addition. Renovation by itself means renewing a facility for the same functional use, whereas renovation conversion means that the purpose and use of the facility is being changed during renovation.

Building renovation requires capital investment, and capital investment decisions require thorough analysis. The analysis should include an evaluation of buildings to determine whether there is a need for renovation, and, if so, which renovation alternative is best.

During the facilities planning process, the total facility requirements are identified. These include both the new requirements and requirements to address any deficiencies in the existing facilities inventory. After facility requirements are developed, the next step is to prepare investment plans meeting those requirements. This involves analysis of the requirements, identification of the alternatives for satisfying the requirements, evaluation and comparison of the alternatives, and selection of the best of the feasible alternatives. Renovation is one of the possible alternatives.

Buildings possess a complex set of attributes, so planning for the most efficiency cannot be an exact science. One objective of Army installation master planners is to identify real-property deficiencies and provide least-cost alternatives to satisfy them effectively. Planners must adequately evaluate the feasible alternatives. Army policy is to maximize use of existing adequate facilities and dispose of unneeded facilities (AR 405-70). This policy minimizes the need for M&R dollars while providing facilities adequate to satisfy Army requirements. However, it requires the evaluation of the existing facilities for functional and physical adequacy.

During the planning stage, there are always a number of ways to achieve the same objective. Often, planners are faced with solving a multicriterion problem. Alternatives based on highly uncertain assumptions, forecasts, or cost estimates can lead to uncertainties in the life-cycle cost estimates on which the overall decision is being based. Forecasting future traffic patterns, for example, or estimating the salvage value of a facility during turbulent economic or political times, includes a large degree of uncertainty in the calculations. Most of the benefits of facility construction and renovation are functional, and qualitative in nature. Although some qualitative benefits can be expressed in monetary terms, it is not possible or practical to express qualitative benefits such as convenience, quality of life, safety, etc., in monetary terms.

Basic questions facility planners must ask themselves about renovation include:

1. How does one determine whether a facility is adequate?

2. Are there any standards?

3. How can one measure the qualitative benefits of facility renovation?

Evaluation of Facilities for Renovation

Theoretically, it may be assumed that with proper construction and maintenance, the life of a building could be extended almost indefinitely. In practice, however, buildings tend to have a finite lifespan. They are frequently built to less-than-optimal specifications. Furthermore, its functional performance in relation to the user's current needs often determines how usable it is considered. The economic possibilities of meeting new needs also play a major role in determining the usability of a building. Therefore, buildings may become obsolete for three different reasons: physical deterioration, functional obsolescence, or economic obsolescence (Stone 1976).

Physical Obsolescence

In this condition, the building is no longer useful due to its physical deterioration. Most buildings have quite a long physical life, even with less-than-adequate maintenance. *Physical life* is defined as the life of the building's identity as an individual useful structure, not the life of one or more of its physical parts. The length of time over which it is worthwhile to continue M&R depends on how well the building meets the needs of the functions to be performed within it, and how economical it is to operate the building. Most buildings never reach the point of physical obsolescence; they are demolished for other reasons.

Functional Obsolescence

This is defined as the point at which a building can no longer satisfy the functional requirements of the user. Because operations and equipment change over time, so do a facility's functional requirements. If the facility is no longer useful to perform its intended mission, then it is functionally obsolete. Since activity costs (e.g., personnel salaries, equipment) are much higher than space costs, functional suitability is very important.

Economic Obsolescence

This is defined as the point at which a building is no longer economically efficient to use. A building is considered worth repairing or renewing if the value obtained through renovation is greater than the value that could be obtained by demolishing the building and erecting a new one. Sometimes it makes good economic sense to demolish a physically sound building, if the building is no longer needed. In some cases, conversion of the building to a new use may be more economical if there is a need for such a conversion. Usually, maintenance costs are not high enough to seriously shorten the economic life compared to its potential physical life. More frequently, a building's economic life is shortened because facility needs can be met more economically by rebuilding or some other method.

The Decision To Renovate

When a building reaches one of the stages discussed above, it is time to renovate (if renovation is the least-cost alternative). Physical, functional, and economic obsolescence are closely interrelated. By the time a building is physically obsolete, it might already have been functionally and economically obsolete for some time. Properly maintained facilities reach economic and functional obsolescence before they reach physical obsolescence (Stone 1976). This implies that functional or economic obsolescence drive most building renovation decisions.

The evaluation of buildings for capital investment decisions such as renovation depends largely on whether the building is used by the corporate sector, the public sector, or for residential purposes. Each sector has different criteria and motivations for making renovation decisions.

In the corporate sector, a facility is considered just another cost factor in production. Investment decisions such as renovation are the result of the evaluation of competing capital investments and the allocation of capital between them, as illustrated by the break-even chart in Figure 3. As long as there is enough demand to produce at more than *p1 volume*, it is profitable for the firm to be in business. Assume that the fixed costs (Fc) are primarily facility costs. If market demand requires less than *p1 volume*, the cost to produce is more than the revenue it can generate, which makes the facility worthless economically. If there is a market for considerably more than *p2 volume*, it is profitable for the firm to increase investment on the facilities. The break-even chart is a simple, graphical representation that shows the decisionmaker the effects of changing the values of parameters. However, even business organizations give some thought to a building's appearance over and above its value for business purposes.

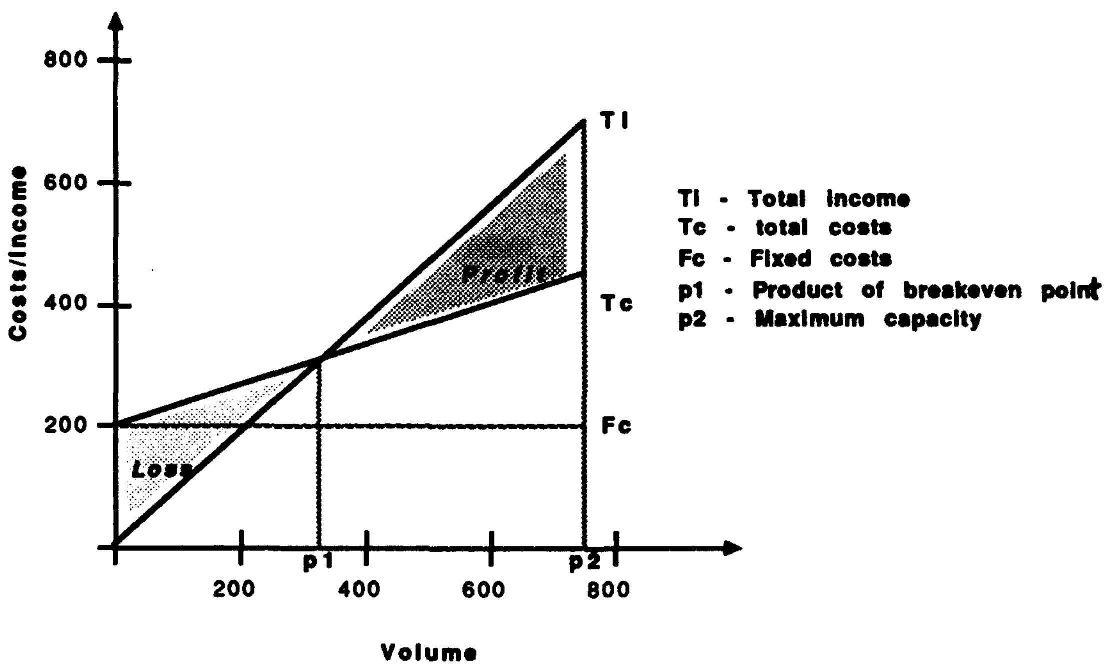

Figure 3. Break-Even Chart.

Occupants value buildings for the satisfactions they provide. Because so many of these satisfactions are personal and subjective, it is probably not possible to develop an objective way to measure occupant satisfaction that applies to everyone.

Army facilities (and other public facilities) are designed to meet specific needs, and those facilities are considered valuable as long as they are functional. The need for a particular facility can be evaluated using Army facility planning criteria, and information on existing facilities and types. Army facilities are rarely required to sell products, and the concepts of price and demand are missing, but "capacity" has a definite meaning. Army building projects are usually undertaken for functional or social reasons, and so the idea of profit as understood in the private sector is also irrelevant. In place of these missing corporate objectives, public facilities generally focus on two other goals: *planning* (to obtain good value for the money spent) and *evaluation* (to determine whether the project is worthwhile).

The decision to renovate, as a capital investment decision, must consider all relevant costs and benefits of a project investment over its full life. The relevant costs include initial investment costs, M&R costs, and operational costs. If properly estimated, the life-cycle cost of a building represents all these costs over the economic analysis period, at an appropriate discount rate. Because Army facilities (and other public buildings) are planned to meet specific needs and are considered to have value as long as they are functional, a number representing a level of functional condition may be treated as an indicator of the overall benefits an owner derives from a facility.

The value of a facility toward satisfying a requirement is determined by its physical condition, functional condition, and the suitability of its location. Physical condition assessment of a facility addresses the condition of the building's components. Condition assessment methods and guidance can be provided by engineered management systems (EMSs) such as BUILDER, developed by the U.S. Army Construction Engineering Research Laboratories (USACERL).

Location is another important factor in determining the usability of a building. Availability of utilities, access roads, and land-use (Army "zoning") compatibility are some of the factors that determine suitability of location. The overall functional value of a facility depends on its functional suitability, physical condition, and location.

The type of information available about a given facility generally pertains to its physical condition. Methodologies for measuring and evaluating functional condition and location suitability are not available. The factors determining functional condition and suitability of location are qualitative, and largely subjective in nature. The development of a methodology to assign a value to these subjective factors is a complex task.

The Decisionmaking Process

Decision analysis methods provide an organized approach to such decisionmaking problems. Structuring complex values in the form of a value tree that hierarchically relates general areas of concern with specific evaluation criteria is the first step of the process (Keeney 1982, pp 803-838). Objectives, attributes, and values have to be identified in the development of the value structure.

The broad overall objective for functional condition evaluation is to determine functional adequacy. Detailed objectives include building layout suitability, engineering systems suitability, safety, security, physical condition, location, etc. These subobjectives are further broken down into lower-level objectives. An attribute is associated with each objective and subobjective to indicate the degree of fulfillment in the particular facility being evaluated.

A comprehensive set of attributes to objectively measure the functionality of a building is being developed at USACERL. The selected attributes are based on Army guidance (DG 1110-3-104; TM 5-803-5), Architectural/Engineering Instructions (AEI) Manual (HQUSACE 1989), *USAREUR*[*] *Space and Planning Manual* (Nakata Planning Group 1983), Army Criteria Tracking System (ACTS), elements of the project development brochure (PDB), American Society for Testing and Materials (ASTM) standards on serviceability of facilities (Ventre 1990), and workshops with installation representatives.

This system of attributes includes a weighting system to indicate the relative importance of each factor. Because most of the attributes are subjective, an index had to be constructed to account for subjectivity. A standard minimum level of functional condition is specified for each attribute to represent the threshold value required for functional condition. Those values are aggregated to obtain an overall score that serves as a minimum required value that must be met before acceptance of a facility as functionally adequate. The overall functional condition score of a selected facility is also obtained in a similar way.

The condition of the facility to meet a general requirement (e.g., housing an administration function) requires general-purpose evaluation of the facility against some criteria, standards, or rules of thumb. The criteria for this kind of evaluation come from Army regulations, standard designs, design guides, or industry standards. Building attributes are evaluated against these criteria to compare and analyze the fulfillment of these objectives or criteria.

The functional condition of a facility to meet the demands of a particular mission requires in-depth analysis of the user requirements. The functional criteria for satisfying user requirements are to be established. The PDB is used to define functional requirements for Army facilities (TM 5-800-3). Intelligent PDB (IPDB) is an automated system that helps users define these functional and technical requirements. The evaluation of a facility against PDB requirements analyzes the functional condition of that facility to satisfy its mission. All special requirements must be taken into consideration in this evaluation.

It can be seen that there is a need to evaluate facilities at different levels of detail to satisfy the planners' different information requirements. If a facility is judged adequate to satisfy its mission requirements, then it is not functionally obsolete.

Economic obsolescence can be evaluated through traditional methods of economic analysis. These include life-cycle cost analysis, break-even analysis, savings-to-investment ratio, discounted payback period, equal uniform annual costs, and net-benefits analysis.

The life-cycle cost method involves the discounting of all expected future negative and positive cash flows to present value using an appropriate discount rate.

Break-even analysis, as discussed previously (Figure 1), is also represented quantitatively, and is applicable mostly to the corporate sector.

Savings-to-investment ratio is used to project the savings to result from an initial investment. It expresses the ratio of discounted savings resulting from the new investment to the original amount of the investment. For an investment to be economically sound, the savings-to-investment ratio must be greater than 1:1 (e.g., 2:1).

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[*]USAREUR: U.S. Army Europe.

Payback period analysis identifies the time required for the cumulative savings from a project to offset the investment costs. Discounted payback period analysis is often used in conjunction with savings-to-investment ratio. Equal uniform annual cost is an approach for evaluating alternatives with an unequal period of analysis. It expresses all life-cycle costs and benefits for each alternative in terms of an average annual expense (Neathammer and MacLean 1988).

The methods discussed so far are helpful for evaluating alternatives in terms of monetary value, but do not provide information on the qualitative factors that must be considered in the decision.

The net-benefits method expands life-cycle cost analysis to include benefits. Because this type of evaluation considers both costs and benefits, it attempts to measure economic efficiency rather than cost effectiveness (which addresses the least-cost solution without considering benefits). The net benefit is calculated as present-value benefits minus present-value costs (Lippiat and Weber 1992). Net-benefit analysis requires benefits to be expressed as monetary values, but some qualitative factors are impossible to evaluate in monetary terms. One proposed new facility may fit better into the landscape than another, but this advantage may be impossible to express in monetary terms.

P.A. Stone suggests the costs-in-use technique, which puts all measurable components on one side of the balance (in the form of cost items), to be evaluated against a value judgment on appearance, comfort, and convenience (Stone 1980). He describes the costs-in-use technique to estimate the cost consequences of building designs against which the subjective judgments of appearance, comfort, and convenience can be set.

Multiattribute decision analysis permits more than one criterion to be considered in a decision. This approach provides an alternative to developing monetary measures of qualitative benefits, as required by net-benefit analysis. Multiattribute analysis limits the effect of subjectivity in the costs-in-use technique by using a structured decision-analysis approach.

When a need for renovation is determined, all feasible renovation alternatives must be identified. Life-cycle cost data and the functional condition index of the alternatives should be used to identify the best one.

The steps of the renovation decision process may be summarized as follows:

1. Conduct a utilization survey and requirements analysis to determine whether the facility is needed. If the facility is not needed, it is assumed that it will be disposed of. If the facility is needed, the following steps are required.

2. Assess the functional condition of the facility. If it is functionally adequate and economically efficient, then it does not require renovation. The decision-support model being developed at USACERL will be useful to evaluate the functional adequacy of a facility. Economic analysis can be used to compare the life-cycle costs of the alternatives to those of the *status quo*, to evaluate the economic efficiency.

3. Identify all alternatives to renovation for the facility. Relocation, renovation of other facilities, diversion, conversion, lease, and new construction are the possible alternatives.

4. Assess the functional adequacy of each alternative. If the functional adequacy of any alternative is below the threshold value, then it is not a sound alternative. This step identifies the feasible alternatives.

5. Perform economic analysis on the feasible alternatives. Compare the life-cycle costs and functional adequacy values of the alternatives, then select the most desirable alternative.

Tools Available To Assist in Renovation Decisions

The authors surveyed the literature and other sources to determine the current availability of systems, models, and technologies for supporting building renovation decisions. Several computer systems and models for general facility planning and management are available. They range from simple information management systems to expert systems. There are building inventory management systems, maintenance management systems, and planning criteria tracking systems. Survey findings indicate that there is little research underway dedicated to evaluation of the functional condition of facilities. The following sections summarize the findings.

BUILDER

The BUILDER system is being developed by USACERL to help managers effectively maintain the physical components of a facility. The goal of this system is to use engineering technology to determine when, where, and how best to maintain facilities. It establishes building maintenance, physical condition, and performance standards. It requires knowledge of the building sizes, types, interrelationships of component parts, and the condition of the physical components. Following inspection, each BUILDER-defined component will be assigned a condition index rating. The Building Condition Index (BCI) would be established by aggregating the component indexes into a single composite index for an entire building. It uses database technology for decision support.

XPLANNER

XPLANNER is a knowledge-based decision-support system for the areas of facility management and planning. It was developed as a research project for selected facilities, and is not fully implementable to cover all Army facility types. The focus is on urban planners and their problem-solving tasks. The XPLANNER classifies facilities into several categories, based on physical condition. It estimates facility requirements using its knowledge about the space allocation standards. XPLANNER is an integrated decision-support system using database management technology, expert system technology, and modeling techniques.

Intelligent Project Development Brochure (IPDB)

A project development brochure, or PDB, is a document used in Military Construction, Army (MCA) projects to communicate the unique requirements of facilities to the architects who will design them. Information about the needs of the future users of the facilities is gathered, processed, analyzed, and documented during this predesign stage in PDB. IPDB is a system developed by USACERL to automate most of these tasks and prepare the PDB. The system helps determine the requirements of the facility using data about the activities, equipment, and personnel of the intended occupants. The content and intelligence of the system come from Army regulations, technical manuals, design guides, and other literature. The finished PDB generated by IPDB contains functional and technical requirements of the facility users.

ECONPACK

ECONPACK is a computer-based economic analysis system that performs life-cycle cost calculations such as net present value, equivalent uniform annual cost, savings-to-investment ratio, and discounted payback period. It has the capability to perform cost-sensitivity analysis and discount-rate-sensitivity analysis. The output reports conform to current Department of Defense (DOD) guidance on project planning and capital investment decisions. The purpose of these economic analyses is to identify the least-cost alternative using life-cycle costs.

Other Related Systems and Research

ACTS and the Facilities Planning System provide criteria and requirements for typical facility types listed in AR 415-28. Design Criteria Information System (DCIS) provides design criteria to the designers of typical facility types. The Real Property Planning and Analysis System (RPLANS) provides planners with analysis tools integrating the above criteria tracking systems, cost-estimating databases, and building inventory management systems (Integrated Facilities System-Mini/Micro [IFS-M], Desktop Resource for Real Property [DR-REAL]).

ASTM Subcommittee E06.25 is developing rating scales for comparing the performance and serviceability of office facilities.

All the above systems and models were developed for a specific task: BUILDER for M&R decisions, ECONPACK for economic analyses, and the others to provide general assistance to the planner in analyzing the facility requirements. The only existing system addressing the functional requirements to satisfy a mission is IPDB. Renovation decisions require information and analysis exceeding the capabilities of all the above systems. The Army needs a tool to evaluate user requirements, facility condition, and the economic impact of renovation compared to all other alternatives for satisfying the requirement.

Problem Areas and Requirements for Other Tools

A look at the steps in the renovation decision process reveals problem areas and a need for additional tools. As discussed previously, the first step is to determine need through a utilization survey and requirements analysis. The requirements analysis includes the identification of missions and organizations to be supported, identification of real property requirements and existing assets, and determination of deficiencies and excesses. RPLANS provides most of the necessary tools to perform a requirements analysis, using real property inventory data, stationing data, and facility allowances. All input to RPLANS is quantitative. Qualitative information about facilities (e.g., functional adequacy) is not taken into account in an RPLANS analysis.

Step 2 of the renovation decision process is assessing the facility's functional adequacy. There are no established uniform data on functional adequacy requirements. As mentioned, ASTM Subcommittee E06.25 is working on measuring the performance and serviceability of office buildings, but the authors know of no other research underway on methods for evaluating the functional condition of a facility.

Buildings possess a complex, interdependent set of attributes. Measurement of functional adequacy must include a comprehensive evaluation of these attributes in relation to each other. Because most of these attributes are qualitative and perceived subjectively, objective measurement of functional performance is a very complex task. The more complex the task, the more difficult it is to decide which alternative offers the best value for money.

Rating scales and methods are needed to measure these attributes individually, and to measure the facility's overall functional performance. Such a rating approach, while not empirically exact, does allow one to develop consistent ratings and a structured method to objectively measure overall functional adequacy. However, the guidance, methods, or tools to measure functional adequacy are not available.

Identification of all available alternatives is Step 3 of the decision process. During the planning stage, there is always more than one possible way to achieve the same objective, so the best has to be chosen. The installation can identify the overutilized, underutilized, and vacant facilities from the annual real property utilization survey. If a facility is underutilized, and that category of facilities is underutilized, the facility is not required. The organization or activity may be relocated to a more suitable facility in the same category, and the existing facility can be converted to another use or disposed of. In this hypothetical case, then, relocation to another facility is one possible alternative to renovation of the facility being evaluated.

However, it is also possible that other facilities in that category are not functionally adequate, either. Then renovation of the current facility and renovation (or conversion) of other facilities are possible alternatives. If the facility is fully utilized, but the facility category is underutilized, relocation to a more suitable facility is another possible alternative. If the facility category is overutilized, then compatible facilities in other categories may also be alternatives to renovation of the current facility. Leasing and new construction are two other possible alternatives.

Information on existing assets and off-post facilities are the main sources for identifying alternatives. Facility type, location, condition, utilization, and the availability of leasable off-post facilities are evaluated in the identification of alternatives. IFS-M or DR-REAL provide the information on existing assets. The other information is gathered through special studies and coordination with off-post agencies.

Step 4 of the renovation decision process is to assess the functional adequacy of the alternatives. As discussed previously, if the functional condition of an alternative is below the threshold value, then it is not a sound alternative. Relocation to another facility is not a valid alternative if its functional condition for the selected purpose is below the threshold value. Similarly, the *status quo* is not a valid alternative if the current facility is not functionally adequate. But, renovation of each of these facilities is an alternative since functional condition can be improved through renovation.

Step 5, the final step, is to perform an economic analysis on the feasible alternatives. The life-cycle costs and functional condition values of the alternatives are compared to make an informed decision. ECONPACK can perform several types of economic analysis for comparing life-cycle costs. USACERL Technical Report P-89/08 describes the process, and training for ECONPACK is available through USACE.

3 A VALUE STRUCTURE FOR MEASURING FUNCTIONAL CONDITION

Multiple-Criteria Analysis and Functional Condition

Objective measurement of functional condition in a building is a complex task that involves two basic goals:

1. Selecting a course of action from among multiple alternatives

2. Making the selection based on consideration of multiple criteria.

Normally, an alternative will not perfectly meet all of the relevant criteria. The best alternative is defined by the tradeoffs required between relative value and disadvantages. Such a decisionmaking task requires fairly disciplined procedures and analytical processes to ensure that the best alternative has been selected, based on all available information on the qualitative and quantitative attributes of each. This type of decisionmaking task generally requires multiple-criteria analysis.

Two phases of the analysis and evaluation process play an especially important role in identifying the best course of action in facilities planning and management decisions. The first is a formal analysis of the tradeoffs to determine the functional condition of a facility. A facility will have its own strong and weak points in relation to each of several pertinent objectives, and the task is to systematically and completely assess the functional condition of the facility with respect to those objectives. The second key phase is the estimation of life-cycle costs. While financial criteria such as least-cost are not likely to be the sole determinant of the best course of action, they are sure to play a central role. Life-cycle costs together with functional condition value can determine the best course of action from among several alternatives. Guidance and training on this second phase—the estimation of life-cycle costs—is available through USACE (Neathammer and MacLean 1989). This report focuses on the first of the two phases—the assessment of functional condition.

The broad overall objective of this evaluation is to accurately determine a building's functional condition. Detailed subobjectives include accurate evaluation of building layout suitability, engineering systems suitability, safety, security, physical condition, etc. These subobjectives are further broken down into lower-level subobjectives. An attribute is associated with each one of these low-level subobjectives to help objectively indicate how suitable a facility may be to fulfill its mission.

During the development of these attributes and the hierarchical structure for evaluating functional condition, care has to be taken to include all relevant factors into the analysis while preserving independence among the criteria as much as possible. Independence of attributes is considered a key to the validity of the evaluation process because it helps to avoid putting too much weight on factors included in overlapping criteria.

Categories of Attributes

The functional attributes of a facility, combined with its physical and location attributes, determine the overall adequacy of a facility to satisfy its mission requirements. Figure 4 lists facility condition attributes. Facility condition can be subdivided into physical condition, functional condition, and suitability of location. Physical condition applies to the *overall condition* of the structure and its engineering systems. A component is considered to be in poor condition when repair or replacement is required to bring it back to good operational condition. Functional condition, on the other hand, applies to the

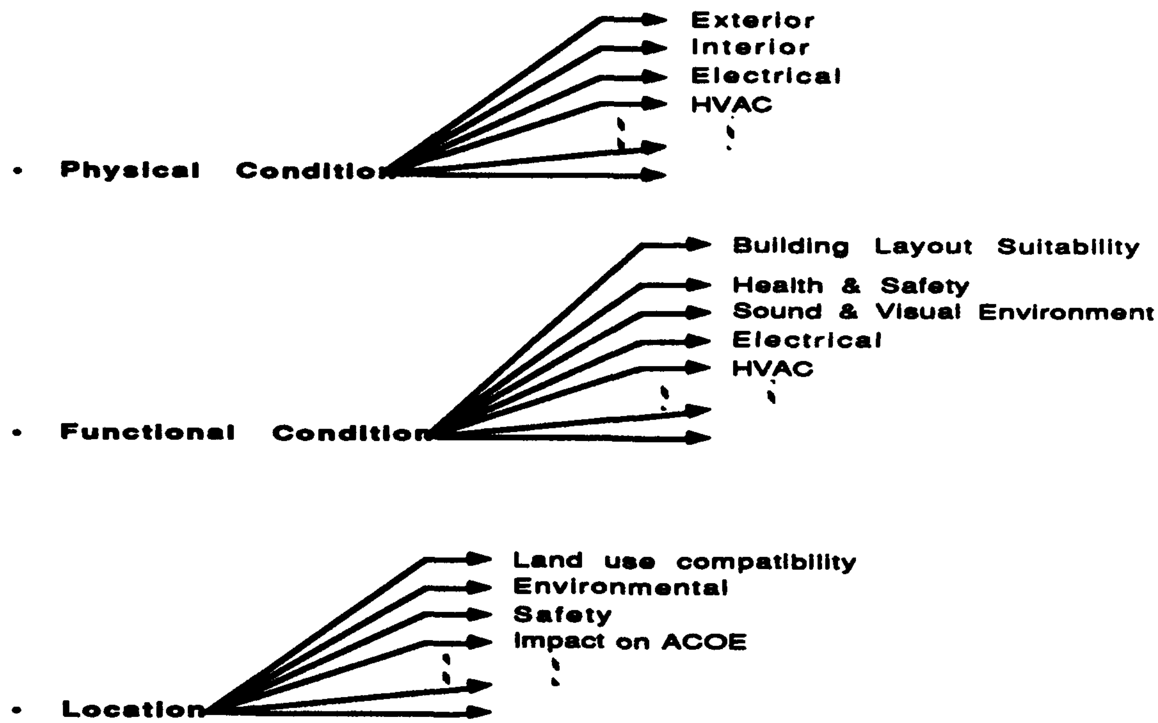

Figure 4. Facility Condition Factors.

usability of that facility for a selected mission, including such characteristics as suitability of building layout, suitability of engineering systems to support mission-related activities, and other factors affecting the usability of that facility for the intended purpose. Suitability of location to the selected mission applies to issues such as land-use compatibility, environmental concerns, zoning, etc.

Physical Condition

A hierarchy of attributes for physical condition evaluation of a facility can be incorporated into engineered management systems (EMSs) such as the USACERL-developed BUILDER (Uzarski et al., July 1990). EMSs define physical attributes as building *components* and *subcomponents*. In BUILDER, the top-level attributes for physical condition evaluation are:

1. Structure
2. Roofing
3. Exterior closure
4. Interior construction
5. Exterior painting
6. Interior painting

7. HVAC system

8. Electrical system

9. Plumbing system

10. Other.

Assessment of these 10 categories of facility components will define the current physical condition and maintenance requirements. A Building Condition Index (BCI) is being developed for BUILDER to help calculate overall building physical condition.

Functional Condition

The following breakdown of building attributes provides a framework for classifying facilities according to the functionality they provide their occupants. Not all attributes apply to all facilities, but taken together, these attributes can represent the overall functional condition of a facility. Seventeen top-level attributes have been identified, some of which include subcategories:

1. Functional spaces
   - Dimensions of functional spaces (quantitative)
   - Layout of functional space

2. Supporting spaces
   - Dimensions of supporting spaces (quantitative)
   - Layout of supporting spaces

3. Ceiling Height

4. Access to material and equipment
   - Width and height of doors
   - Circulation (corridor width, etc.)

5. Handicap access

6. Floors
   - Floor load ratings
   - Floor finishes

7. Health and safety
   - Fire safety
   - Health hazards (asbestos, radon, indoor air pollution, etc.)
   - Operational safety

8. Grounds
   - Parking
   - Accessibility to vehicles
   - Landscaping

9. Sound and visual environment
   - Acoustics
   - Lighting and glare

10. Electrical service and fixtures
    - Building power supply
    - Power distribution
    - Adequacy of fixtures

11. Water and plumbing
    - Water supply
    - Plumbing system

12. HVAC (heating, ventilating, and air conditioning) system suitability
    - Temperature and humidity control
    - Ventilation

13. Built-in equipment

14. Security

15. Communications

16. Environmental impact

17. Aesthetics and image
    - Exterior appearance
    - Appearance of public spaces
    - Appearance of interior spaces.

These 17 top-level attributes can be used (1) to analyze the capability of a facility to perform to a required level of functionality or (2) to compare the functionality of different buildings to perform a specific mission. In other words, these attributes can be used to estimate the functional condition of alternatives. Because the functionality of a building affects the productivity of its occupants, an assessment of functional value must be considered in any economic evaluation of potential capital investment in a facility.

The following paragraphs explain the attributes in more detail.

Functional Spaces

Functional spaces are the spaces needed to perform the required mission. In an administration building, the functional spaces will include office space, conference areas, and other mission-critical spaces. In a warehouse, they will include storage areas, shipping and receiving areas, etc. The suitability of functional spaces is measured both by lower-level quantitative and qualitative aspects: (1) dimensions and availability of functional spaces (quantitative) and (2) layout of functional space (qualitative). The quantitative attribute considers whether the space is available, what its dimensions are, etc. The qualitative attribute addresses the shape of the space, how it is laid out, and to what it is adjacent.

Supporting Spaces

Supporting spaces are the spaces required to support (as opposed to perform) mission-critical functions. These spaces include restrooms, janitor rooms, personnel lounges, and first-aid rooms. Supporting spaces may be dedicated to activities, personnel, or equipment. As with functional spaces, the suitability of supporting spaces is also measured according to quantitative and qualitative criteria.

Ceiling Height

This attribute may be critical to performing required functions—or it may prevent performance of these functions.

Access to Material and Equipment

This attribute is to measure the accessibility of spaces, equipment, and materials within a building. The corridors and access doors are evaluated for accessibility. The lower-level attributes are door dimensions (width and height) and circulation (corridor width).

Handicap Access

This attribute evaluates a facility's compliance with requirements for access by handicapped individuals.

Floors

This top-level attribute evaluates the suitability of a building's floors to perform the required missions. The suitability of floor loads and finishes are evaluated separately as lower-level attributes.

Health and Safety

This attribute is to measure the overall health and safety aspects of a facility. The lower-level attributes are fire-safety features, health implications of building materials or type of construction, and operational safety. Assessment of the facility's compliance with National Fire Protection Association (NFPA) life-safety codes and Army fire-safety requirements are the components of fire-safety attribute. Health hazards from asbestos, chemical fumes, smoke, radon, etc., are evaluated under the health-risk attribute. Safety features related to the building's selected mission are evaluated under operational safety.

Grounds

This attribute addresses the site-related attributes that can affect the use of a facility. This attribute does not evaluate the overall location factors, but addresses specific site-related factors. The lower-level attributes are parking availability, access driveways and curbs, and the condition of landscaping at the site.

Sound and Visual Environment

Distractions or disruptions due to the noise or poor visual environment (too much glare, unattractive paint, etc.) are covered under this attribute.

Electrical Service and Fixtures

The suitability of the electrical system to support a facility's intended mission is covered under this attribute. Power supply, power distribution, and the adequacy of fixtures are the lower-level attributes. Is the power supply sufficient to perform the functions efficiently? Is the facility suitable to perform the required functions with existing power distribution and fixtures?

Water and Plumbing

The suitability of the water supply and plumbing system to perform the required functions is covered under this attribute.

HVAC Suitability

This attribute is for evaluating the suitability of the temperature, HVAC controls, and humidity to performing a facility's required functions. The mechanical condition of the HVAC system itself is not covered under this attribute, but rather the suitability of the indoor environment produced by the system.

Built-In Equipment

If built-in equipment is required for a building's mission, it is evaluated under this attribute. However, this attribute often is not applicable to typical functional uses.

Security

A building's security features are evaluated under this attribute.

Communications

The communications features of the building are evaluated for the functional use of the facility.

Environmental Impact

Environmental impact resulting from the facility's functional use is covered under this attribute.

Aesthetics and Image

This attribute addresses a facility's appearance. Some missions require an appealing view from inside, public spaces that project a good image, and attractive work areas and interior spaces.

Location Suitability

The location attributes selected for this decision-support process were compiled from design guides, the USAREUR space and planning criteria manual, and DCIS. They are:

1. Land-use compatibility
2. Environmental compliance
3. Safety compliance

4. Impact on Army Communities of Excellence (ACOE)

5. Suitability of transportation

6. Suitability of utilities

7. Efficiency of operations.

Location attributes are used to identify the suitability of a location to a facility's mission requirements. They can also be used to compare the suitability of alternative locations. Physical, functional, and locational attributes all should be considered when assessing the usability of a facility, and they can also be used to compare the suitability of alternative facilities to satisfy a particular mission requirement.

Evaluating Facilities for Potential Renovation

Master planners at DOD installations need to plan for occupancy needs. The result of a sound master planning approach will eliminate inefficiencies in facility layout and maximizes return on investment.

Effective facilities planning and management decisions require knowledge of the physical and functional condition of the buildings, facility location, and the economic impact of the alternative decisions. The wealth of tools for helping to evaluate the physical condition of a building includes BUILDER and the Maintenance Resource Prediction Model (MRPM), the latter of which allows the user to maintain facilities by tracking the use and projected replacement dates of their components (Neely et al., July 1989). Another USACERL-developed tool, ECONPACK, can be used to estimate life-cycle costs and to evaluate the economic implications of various possible decisions. However, no tools currently exist to support planning decisions by helping managers systematically evaluate a facility's functional condition and location suitability. The renovation decision support model described in this report will support development of such a tool. The model provides physical, functional, and location condition indexes, including threshold values that indicate adequacy of the pertinent attributes. These indexes can be used in decisionmaking. If a facility is adequate in physical condition, functional condition, and location suitability, then the facility is adequate for its specified mission and there is no need to renovate. Even if the facility needs minor repair or routine maintenance work, major renovation work is not required if the physical, functional, and location indexes are satisfactory.

If the location of a facility is *not* adequate to perform the required mission, then renovating it to fulfill that mission is not advisable. The facility may be more suitable for other uses. The planner can evaluate the location for more suitable uses and perform a requirements analysis to determine whether the facility is adequate for those uses. If it does not appear to be economically efficient to convert it or divert the facility to other uses, the building may be a good candidate for disposal.

If the location of a facility *is* suitable but the overall condition is not adequate, then it is a candidate for renovation. Whether the functional condition is not adequate or the physical condition is poor, renovation may be a feasible alternative.

In short, renovation of a building is an appropriate solution under the following conditions:

1. Other facilities in that mission category group are not underutilized

2. The location of the facility is suitable to perform the mission

3. The facility is functionally or physically inadequate

4. It is economically efficient to renovate that facility compared to other alternatives.

The functional performance of a facility can be evaluated at different levels of detail. It may be evaluated either against industry standards or Army standards for general-purpose evaluation. Industry standards, Army standard designs, design guides, etc., provide general guidance and criteria for functional facilities. The correspondence of facility attributes with those criteria is evaluated in general-purpose evaluation. Correspondence of facility attributes with *user* requirements, however, is evaluated in special-purpose evaluation. Evaluation criteria come from the PDB or user requirements in such a case. Evaluation methods and decisionmaking processes are similar for both general-purpose or special-purpose evaluations, as shown in Chapter 4.

Characteristics of the Facility Inspection Process

As previously noted, facility condition assessment for strategic decisions such as renovation, disposal, or conversion require physical condition assessment as well as functional and location suitability assessment. However, physical condition assessment alone can determine only routine maintenance management decisions. Physical condition assessment methods are discussed in USACERL Technical Report M-90/19, which describes the BUILDER EMS (Uzarski et al., July 1990). This section describes inspection methods for functional and location suitability.

The attributes for assessment of functional condition or location suitability are mostly qualitative factors. A classification and rating procedure is needed to measure these attributes as objectively as possible. A proposed set of functional and location suitability attributes and rating procedures is presented in Chapter 4. The scales and the rating procedures are developed to support executive-level strategic decisions for any type of facility. Actual criteria may differ by facility type, as may the importance of a particular attribute in the overall decisions. Using general strategic rating procedures to guide and structure the evaluation is a very practical approach because the universal attributes may be weighted to reflect the requirements of any particular facility type or case.

The classification and rating procedure proposed in Chapter 4 can be applied to facilities regardless of differences in age, facility type, construction type, or shape. This classification system is not affected by changes in the standards or complexity of the requirements. The system can be used by any person with enough knowledge of facilities to identify their features and understand their mission requirements.

Special professional expertise, such as a degree in architecture or engineering, is not required for assessing most of the functional condition attributes. Familiarity with Army regulations, standard design features, and design guides will help the inspector, and knowledge of the criteria is required. Professional expertise is required to inspect and evaluate certain attributes, such as health and safety features, engineering systems, security, and communications. Evaluation of location suitability also requires professional judgment.

The inspector compiles functional and location "scores" for the facility, based on the pertinent rating scales. Each attribute has a threshold value that defines the minimum requirement for an acceptable rating. The threshold values are listed in Chapter 4 with the rating scales. The scores set for a facility during evaluation are compared with the threshold values.

The rating scale is graded into condition codes ranging from *excellent* to *failed*. "Excellent" means that the condition exceeds the target requirement for that attribute. "Failed" means the condition does not meet the threshold value. In other words, a rating of *failed* means renovation is required before the facility meets the mission requirements. The rating for any given attribute may fall at either extreme, or anywhere in between. A numeric value is assigned to all conditions on the rating scale.

This approach can be taken to determine the functional and location suitability of a specific facility to satisfy a mission requirement, and is also useful for comparing different facilities being considered for the same purpose.

4 RATING SCALES FOR FACILITY ATTRIBUTES

A rating scale has been developed to help planners and managers determine a facility's functional condition and location suitability for its mission requirements. A set of ratings can be compiled using the criteria outlined in this chapter. These criteria can be used either to rate a facility against the threshold (minimum acceptable) values or to rate the suitability of two or more possible alternative facilities. Because each facility option has various capabilities, strengths, and weaknesses pertaining to project requirements, selection of the best option requires value measurement and tradeoff analysis. The ratings resulting from the inspection criteria discussed here will provide an objective basis for selecting the best available facility for a particular mission. They will also help to define the facility's renovation requirements for that mission.

As discussed in Chapter 3, functional performance may be assessed either through a *general-purpose evaluation* or a *special-purpose evaluation*, depending on mission requirements. General-purpose evaluations are made using Army standards or industry standards as the measure. Special-purpose evaluations are made using criteria in a PDB or specific user needs not addressed through a general-purpose evaluation.

The special-purpose evaluation is conducted the same as a general-purpose evaluation. The following rating scales apply to both kinds of evaluation—the standards for the special-purpose evaluation may include requirements found only in the PDB or other applicable documents.

Physical Condition

As discussed in Chapter 3, criteria and ratings indexes for the physical condition of facilities are being developed as part of USACERL's BUILDER EMS. Documentation of these indexes will be published upon completion of BUILDER development. The BUILDER condition indexes will directly support the inspection and rating of a building's physical condition.

Functional Condition

The criteria that follow reflect the refinements of the authors' original set, as explained in Chapter 1 under "Approach."

1. Functional Spaces

Dimensions of Functional Spaces (Threshold Value: 6)

This attribute is used for quantitative analysis of functional spaces. Do not address shape or other architectural features in this evaluation. Use AR 405-70 as criteria for all office spaces. Evaluate other spaces using applicable Army criteria. If criteria are not available, use analytic methods recommended in Army design guides or other space planning literature.

Good (8 points). The facility includes all the functions (organizational activities) recommended in the Army design guide or industry standards for a facility of its type. It satisfies all Army criteria. The functional spaces' dimensions are about the same or exceed industry standards or design guide recommendations.

Moderate (6 points). The facility lacks some of the functional spaces recommended in the Army design guide or industry standard. The shortage of space is less than 10 percent, and the facility is usable with acceptable operational efficiency. It is possible to use the space efficiently with reorganization of equipment, furniture, or with substitution of functional spaces.

Poor (4 points). The facility lacks some of the functional spaces recommended in the applicable design guide or industry standard. The space shortage is between 10 and 20 percent, and it cannot be used without loss of efficiency.

Very Poor (2 points). The facility is missing many of the functional spaces recommended in the design guide or industry standard. The space shortage is 20 to 30 percent and would be highly inefficient to use as is.

Failed (0 points). The facility lacks most of the functional spaces recommended in the design guide or industry standard. The space shortage is more than 30 percent, and it cannot be used without expansion.

Layout of Functional Space (Threshold Value: 6)

Good (8 points). The layout of functional spaces is perfect for this type of facility. The functional adjacencies are suitable according to Army standard designs or design guide recommendations for a facility of its type.

Moderate (6 points). The layout of functional spaces differs from the layout recommended in Army standard designs or design guides. The spaces can be used without loss of efficiency. The functional adjacencies are suitable.

Poor (4 points). The layout of functional spaces differs from the layout recommended in standard designs or design guides. The spaces cannot be used without loss of efficiency, but the functional adjacencies are suitable.

Very Poor (2 points). The layout of functional spaces is not suitable to perform the required functions according to the recommendations in standard designs or design guides. The spaces cannot be used efficiently, and the functional adjacencies are not suitable.

Failed (0 points). The layout of functional spaces is completely unsuitable to perform the required functions. It would be impossible to use the facility in its current layout without renovating the existing functional spaces.

2. Supporting Spaces

Dimensions of Supporting Spaces (Threshold Value: 6)

Good (8 points). The facility has all supporting spaces recommended by industry standards or Army design guides.

Moderate (6 points). The facility lacks some of the supporting spaces recommended by industry standards or Army design guides, but the facility is usable without loss of efficiency.

Poor (4 points). The facility lacks some of the supporting spaces recommended by industry standards or Army design guides. It is usable but not very efficient.

Very Poor (2 points). The facility lacks most of the supporting spaces recommended by industry standards or Army design guides. It would be very unproductive to use the facility without adding more supporting spaces.

Failed (0 points). The facility lacks most of the supporting spaces recommended by industry standards or Army design guides. It does not even have the minimum required supporting spaces for basic operations. It would be impossible to use the facility without adding more supporting spaces.

Layout of Supporting Spaces (Threshold Value: 6)

Good (8 points). The location and layout of supporting spaces are suitable according to the recommendations in applicable Army design guides or industry standards.

Moderate (6 points). The location and layout of supporting spaces do not conform to the recommendations in applicable design guides or industry standards, but the facility is usable without loss of operational efficiency.

Poor (4 points). The location and layout of supporting spaces do not conform to the recommendations in design guides or industry standards, and the facility is not usable without loss of operational efficiency.

Very Poor (2 points). The location and layout of the supporting spaces are not suitable. They do not conform to the recommendations of design guides or industry standards, and it would be very unproductive to use this facility without renovation.

Failed (0 points). The location and layout of the supporting spaces are completely unsuitable. It would be impossible to use this facility without renovation.

3. Ceiling Height

General Criteria (Threshold Value: 6)

Good (8 points). Ceiling height is the same as that specified in industry standards or Army design guide recommendations.

Moderate (6 points). Ceiling height is higher than industry standards for the particular facility, but the difference is less than 2 ft. The facility can be used without loss of operational efficiency.

Poor (4 points). The ceiling height is not suitable for some mission functions in some areas. The facility is usable, but difficulties and disruption of activities will result.

Very Poor (2 points). The ceiling height is not suitable to support intended uses in most parts of the building. It would be very unproductive to use this facility for this purpose.

Failed (0 points). The ceiling height is lower than the Army or industry standard, and the facility cannot be used for the intended mission without renovation.

4. Access to Material and Equipment

Width and Height of Doors (Threshold Value: 6)

Good (8 points). The width and height of all doors equal industry standards or Army design guide recommendations.

Moderate (6 points). The width and height of some doors are smaller than Army or industry standards, but the facility can be used without loss of efficiency.

Poor (4 points). The width and height of some doors are smaller than Army or industry standards, and some of the doors must be modified to avoid inefficiency.

Very Poor (2 points). The width and height of most doors are smaller than Army or industry standards, and they must be changed to perform work.

Failed (0 points). The width and height of most doors are smaller than Army or industry standards, and it would be impossible to use this facility without major repair or renovation.

Circulation (Threshold Value: 6)

Good (8 points). The width of all corridors and aisles is the same as that specified by industry standards or Army design guide recommendations.

Moderate (6 points). The width of some corridors or aisles is greater than Army or industry standards while others conform to Army or industry standards. The facility can be used without loss of efficiency.

Poor (4 points). The width of most corridors or aisles is greater than Army or industry standards for this type of facility. Much space is wasted, but the facility can be used without loss of operational efficiency.

Very Poor (2 points). The width of many corridors or aisles is not suitable to support the required mission functions. The facility can be used only with loss of efficiency.

Failed (0 points). The width of many corridors or aisles is smaller than Army or industry standards, and it is not possible to use the facility without considerable renovation.

5. Handicap Access

General Criteria (Threshold Value: 6)

Good (8 points). All handicap access requirements are met according to applicable codes, industry standards, and Army regulations. The facility exceeds all minimum requirements.

Check the Architect/Engineer Instruction (AEI) manual or Design Criteria Information System (DCIS) for Army handicap access requirements.

Moderate (6 points). The facility meets all minimum code requirements, including the minimum Army handicap access requirements.

Poor (4 points). Some areas require improvement of handicap access features to satisfy Army, industry, or community requirements, but the violations are minor. The facility is usable and all approvals are available.

Very Poor (2 points). The facility requires improvement of some handicap access features to satisfy applicable codes and regulations. Improvements and minor repair are needed before the facility may be used.

Failed (0 points). The facility does not meet handicap access requirements of the Army, industry, or the community. It is not possible to use the facility without major repair or renovation of the building.

6. Floors

Floor Loads (Threshold Value: 4)

Good (6 points). The floor loads are suitable for the facility's intended mission. They conform to industry standards or Army design guide recommendations.

Moderate (4 points). The floor loads are mostly suitable for the building's intended mission. The floor loads in some areas do not conform to industry standards or design guide recommendations. They are suitable for limited functions in those areas. With some reorganization of equipment and functions, the facility can be used without loss of operational efficiency.

Poor (2 points). The floor loads are not suitable for the intended mission in some areas of the facility. They do not conform to Army design guide recommendations or industry standards, and some repair will be required to use the facility.

Failed (0 points). The floor loads are not suitable for the intended mission and they do not conform to Army or industry standards. Major repair or renovation would be required to use the facility for the intended mission.

Floor Finishes (Threshold Value: 6)

Good (8 points). Floor finishes exceed industry standards or design guide recommendations.

Moderate (6 points). Floor finishes are suitable for the facility's intended mission. They conform to applicable industry standards or Army design guide recommendations.

Poor (4 points). Floor finishes are below industry standards, but the floor is usable.

Very Poor (2 points). Floor finishes are not suitable in some areas. Some of the floor finishes need to be modified.

Failed (0 points). Floor finishes are not suitable for the specified mission, so the facility cannot be used without refinishing the floors.

7. *Health and Safety*

Fire Safety (Threshold Value: 4)

Excellent (8 points). The building's fire-safety features exceed NFPA life-safety code and Army requirements.

Exits, sprinklers, egress route, fire zones, travel distance to exits, and all other fire-safety features (by occupancy type) must be evaluated by a fire-safety professional familiar with Army facility safety requirements.

Good (6 points). The building meets all applicable NFPA life-safety codes and Army fire-safety requirements.

Moderate (4 points). The building fails to satisfy some NFPA life-safety codes or Army fire-safety requirements, but the code violations are minor enough that waivers may be granted.

Poor (2 points). The building fails to satisfy some NFPA life-safety codes or Army fire-safety requirements. The violations are significant and may require some minor repair work.

Failed (0 points). The building fails to meet many NFPA life-safety codes and Army fire-safety requirements. It cannot be used without major repair work or renovation. Major repairs would include such work as changing corridor widths.

Health Risks (Threshold Value: 4)

Good (6 points). The building is in perfect condition and poses no health hazards. Materials associated with health risks were not used in construction. The building is free of asbestos, toxic fumes, smoke, radon, and other health hazards. All applicable permits have been obtained.

Moderate (4 points). The building poses no health hazards if used and maintained properly. All applicable permits have been obtained.

Poor (2 points). The building poses some health hazards that require repair work to be done before the building is occupied.

Failed (0 points). Renovation or major repair work is required to make the building usable and safe.

Operational Safety (Threshold Value: 4)

Good (6 points). The building is operationally safe for a facility of its type. The building has all safety design features recommended for a facility of its type and mission. Explosives safety, chemical spills, and other operational accidents are considered in the facility design, and there are redundant safety design features to allow for human errors.

Moderate (4 points). The building is safe for a facility of its type and mission if it is used and maintained properly. The building satisfies all applicable minimum safety requirements, but does not have redundant safety features that allow for human errors.

Poor (2 points). The building fails to satisfy some operational safety requirements, and requires minor repair work to make it safe.

Failed (0 points). The building does not have the safety design features required for its type and mission. Renovation is required to make the building usable.

8. *Grounds*

Parking (Threshold Value: 4)

Good (6 points). The building has plenty of parking space for visitors, staff, and organizational vehicles.

Moderate (4 points). There is shortage of parking spaces during peak business hours, but the shortage is less than 10 percent below the required number. Other areas are available to park the extra vehicles, so the shortage causes little inconvenience.

Poor (2 points). The parking space shortage exceeds 10 percent. Finding a parking space near the building is difficult..

Failed (0 points). Parking is a big problem. The building is not usable without additional parking spaces.

Vehicular Access (Threshold Value: 4)

Good (6 points). Access driveways are well designed to meet the building's functional requirements. Access and clearance are provided for emergency vehicles such as fire trucks. The design and condition of vehicular access are perfect according to AEI and installation design guide recommendations.

Moderate (4 points). Access driveways are somewhat suitable to meet the building's requirements. Access and clearance for emergency vehicles such as fire trucks are provided. The design and condition of vehicular access are usable.

Poor (2 points). Access driveways are usable with difficulty. Access and clearance for emergency vehicles such as fire trucks is difficult. The design and condition of vehicular access is out of compliance with AEI and installation design guide recommendations. Access is possible only with difficulty and loss of operational efficiency.

Failed (0 points). Vehicular access is completely inadequate without major repair of access driveways.

Landscaping (Threshold Value: 4)

Good (6 points). The facility is well landscaped with trees, shrubs, and lawn. All trees and shrubs are trimmed. The view is good and there are no obstructions to site surveillance or emergency vehicles. There are no drainage problems.

Use the site-development section in the AEI and installation design guide as reference.

Moderate (4 points). The facility is landscaped, but the landscaping is not well organized. Some work is required to clean and trim the trees and shrubs, and some planting is required to provide good view. There are no drainage problems. Overall, the existing landscaping is usable with some minor repairs.

Poor (2 points). The facility is not fully landscaped, and additional planting is required. Some soil erosion or drainage problems are evident.

Failed (0 points). The landscaping is completely inadequate without regrading or replanting the site. Drainage and soil erosion problems need to be fixed. Major sitework is required.

9. Sound and Visual Environment

Acoustics (Threshold Value: 4)

Good (6 points). There are no distractions or disruptions due to noise, either internal or external.

Moderate (4 points). Distractions or disruptions due to noise are minimal.

Poor (2 points). Some loss of productivity is expected due to high levels of noise, whether internal or external.

Failed (0 points). The facility is too noisy to function effectively for its selected mission without extensive renovation to mitigate noise.

Visual Environment (Threshold Value: 4)

Good (6 points). The visual environment is completely suitable, with good, nonglare light sources wherever required.

Moderate (4 points). The visual environment is acceptable to support the facility's mission. Light sources create minimal glare, but it does not affect the occupants' work performance.

Poor (2 points). The visual environment is poor, and light sources create enough glare to affect the occupants' work performance. Some loss of productivity is expected.

Failed (0 points). Very poor visual environment and glare make the facility unusable. It cannot be used without renovation.

10. Electrical Service and Fixtures

To adequately assess this attribute, the inspector must be knowledgeable about electrical code requirements. Electrical power requirements for the facility type and designated function are evaluated against all applicable electrical code requirements.

Building Power Supply (Threshold Value: 4)

Good (6 points). Power supply is sufficient to meet the facility's near-term and long-term needs.

Moderate (4 points). Power supply is sufficient to meet near-term needs only.

Poor (2 points). Power supply is not sufficient for the facility's intended mission. The facility can be used with some loss of productivity. If the inadequacy of the power supply creates a potential safety problem, the facility should be rated as failed.

Failed (0 points). The power supply is completely inadequate to support the facility's intended mission. The facility is not usable without renovation.

Power Distribution (Threshold Value: 6)

Good (6 points). Power distribution is sufficient to support the facility's intended mission functions. Plenty of electrical power sources (outlets, etc.) are available, and the power distribution system meets all applicable electrical code requirements.

Moderate (4 points). Power distribution is not sufficient in some areas of the facility. The facility can be used for its intended purpose, but some areas are suitable only for limited functions.

Poor (2 points). Power distribution is not sufficient to support the facility's mission functions. The facility can be used only with loss of productivity. If the inadequacy of the power distribution system creates a potential safety problem, the facility should be rated as failed.

Failed (0 points). The power distribution system is completely inadequate to support the facility's mission functions. The facility is not usable without renovation.

Adequacy of Fixtures (Threshold Value: 6)

Good (6 points). Electrical fixtures are sufficient and well installed to support the facility's intended mission. All types of electrical fixtures needed to effectively support mission functions are installed and in good condition. All fixtures meet all applicable electrical code requirements.

Moderate (4 points). Electrical fixtures are not adequate in some areas of the facility. The facility is usable for its intended purpose, but results in some inconvenience or loss of efficiency.

Poor (2 points). Electrical fixtures are not adequate in most areas of the facility. Some minor repair work is required before the facility can be used for its intended purpose. If the inadequacy of the fixtures creates a potential safety problem, the facility should be rated as failed.

Failed (0 points). There are not enough electrical fixtures to support the facility's intended mission functions. The facility is not usable without major repair or renovation.

11. Water and Plumbing

Water Supply (Threshold Value: 4)

A person with reliable knowledge of water supply and pressure requirements is needed to evaluate this attribute.

Good (6 points). Water supply is sufficient to meet near-term and long-term requirements. The facility satisfies all applicable building codes and Army requirements for water supply and pressure (including fire codes). Both quantity and pressure are evaluated.

Moderate (4 points). Water supply is sufficient to meet only near-term requirements. The facility satisfies all applicable building codes and Army requirements for water supply and pressure (including fire codes) for near-term use.

Poor (2 points). All permits necessary have been granted to use this facility with the existing water supply, but the water supply is inadequate to support the facility's intended mission functions. The facility can be used only with inconvenience or loss of productivity. If the inadequacy of the water supply creates a potential safety problem, the facility should be rated as failed.

Failed (0 points). The water supply is completely inadequate to support the facility's intended mission without major repair or renovation.

Plumbing System (Threshold Value: 4)

Good (6 points). The plumbing system will fully support the facility's intended mission functions. All required plumbing fixtures are installed, of good quality, and in good condition. The facility meets all applicable plumbing codes.

Moderate (4 points). The plumbing system is acceptable. Design and layout are adequate to support mission functions without loss of productivity.

Poor (2 points). Not all required plumbing fixtures are available. The design and layout of plumbing fixtures do not effectively support the intended mission functions of the facility. The facility can be used for its intended mission only with some loss of productivity.

Failed (0 points). There are not enough plumbing fixtures to adequately support the facility's intended mission. The facility is not usable without major repair or renovation.

12. HVAC System Suitability

Temperature and Humidity (Threshold Value: 4)

Good (6 points). Temperatures are comfortable and targets are met throughout the facility. Humidity control is provided where required, and it is effective.

Moderate (4 points). Temperatures throughout the facility are within an acceptable comfort range and are acceptable for functional use of the facility most of the time. Temperature and humidity targets are met most of the time. Humidity control is partially effective. A few portable fans or space heaters may be needed to make some spaces comfortable.

Poor (2 points). Temperature targets are not met in some parts of the building during very cold or very hot days. The building is usable for its intended mission, but productivity is reduced when the outside temperature is very hot or cold. Humidity control is partially effective. Portable fans or space heaters are used commonly throughout the facility to keep thermal comfort at acceptable levels.

Failed (0 points). Temperatures are consistently uncomfortable. The facility will not effectively support mission functions without major repair or renovation work.

Ventilation (Threshold Value: 4)

Good (6 points). The ventilation is well designed to support the facility's mission functions. The air is fresh at all times in all areas of the building.

Moderate (4 points). The ventilation design is acceptable for the facility's intended mission. The air is fresh most of the time in most areas of the building. The ventilation supports operating the facility without loss of productivity.

Poor (2 points). The ventilation design is not fully suitable for functional use of the building. The facility is usable for its intended function but some loss of productivity may result.

Failed (0 points). The ventilation design is not suitable to support the building's intended mission without renovation.

13. Built-In Equipment

General Criteria (Threshold Value: 4)

Good (6 points). The built-in equipment is well designed and installed to support the facility's intended mission.

Do not include HVAC equipment in this evaluation, but inspect all other kinds of built-in equipment.

Moderate (4 points). The built-in equipment is usable with no loss of productivity. For equipment-sensitive facilities such as manufacturing or industrial plants, any built-in equipment not in good condition should be rated poor.

Poor (2 points). The built-in equipment is usable, only with a loss of productivity.

Failed (0 points). The built-in equipment is not adequate to support the building's mission functions without major repair or renovation.

14. Security

General Criteria (Threshold Value: 4)

Good (6 points). All security features included in the facility design comply with Army regulations. Systems include redundancies to effectively mitigate human errors. The facility meets or exceeds all security requirements.

Moderate (4 points). The security features are acceptable for the facility's intended mission.

Poor (2 points). The security features are not fully adequate for the facility's intended mission functions. Minor repairs are required.

Failed (0 points). The security features are completely inadequate for the facility's intended mission. Major repairs or renovation are required.

15. Communications

General Criteria (Threshold Value: 4)

Good (6 points). The facility has a state-of-the-art communications system that fully supports the facility's intended mission.

Moderate (4 points). The communications system is acceptable for the facility's intended mission functions.

Poor (2 points). The communications features are not fully suitable for the facility's intended functional use. The facility can be used for its intended mission only with loss of productivity. Some repair or modification is required.

Failed (0 points). The facility cannot be used for its intended mission with the existing communications system. Major renovation of the system is required.

16. Environmental Impact

General Criteria (Threshold Value: 6)

Regulatory compliance requirements are coordinated with Federal, State, and local agencies.

Good (6 points). Environmental impact documentation required by the National Environmental Policy Act (NEPA) shows no environmental hazards. Air quality, water quality, and waste disposal methods are in compliance with Federal, State, and local regulations. The facility satisfies all coordination and compliance requirements of all appropriate agencies.

Poor (2 points). Environmental impact statements require corrective measures before the facility is in compliance. The violations are minor.

Failed (0 points). The facility needs renovation to comply with environmental regulations.

17. Aesthetics and Image

Use Army Communities of Excellence standards for evaluating all three subattributes.

Exterior Appearance (Threshold Value: 4)

Good (6 points). The building exterior is in good condition and looks appealing. The approach and entry provide convenient access and present an excellent appearance.

Moderate (4 points). The building is acceptable in overall appearance. It looks "about average" for a facility of its type.

Poor (2 points). The facility's overall appearance is poor. The building is generally considered unattractive.

Failed (0 points). The building is in very bad shape, with many broken or damaged components. It cannot be used for its intended purpose without major renovation.

Appearance of Public Spaces (Threshold Value: 4)

Good (6 points). The facility's public spaces convey an excellent image, both to occupants and the public. The image is considered excellent in comparison with public spaces in similar facilities and Army Communities of Excellence standards.

Moderate (4 points). The facility's public spaces convey an average image, both to occupants and the public, in comparison with public spaces in similar facilities.

Poor (2 points). The facility's public spaces look substandard compared to public spaces in similar facilities.

Failed (0 points). The condition of the facility's public spaces is completely inadequate without major renovation.

Appearance of Interior Spaces (Threshold Value: 4)

Good (6 points). All interior spaces are in excellent condition. They look newly constructed or very well maintained.

Moderate (4 points). The interior spaces are acceptable in overall appearance, and are considered about average for a facility of its type.

Poor (2 points). The interior spaces have a poor overall appearance, including problems such as dirty walls and windows, or damaged components. The interior spaces are generally considered unattractive.

Failed (0 points). The interior spaces are in very bad shape, with many broken and damaged components. They are not functional without major renovation.

Location Suitability

1. Land-Use Compatibility

The term "land use" in this context refers to the Army equivalent of zoning. Use standards from the USAREUR space and planning criteria manual for compatibility evaluation.

General Criteria (Threshold Value: 4)

Excellent (8 points). The land use is perfectly compatible for support of the facility's mission.

Good (6 points). The land use is compatible with the facility's mission.

Moderate (4 points). The land use is adequate to support the facility's mission.

Poor (2 points). Some aspects of the land use are not compatible with the facility's mission.

Failed (0 points). The land use is completely unacceptable for the facility's intended mission.

2. *Environmental Compliance*

General Criteria (Threshold Value: 4)

Excellent (8 points). Environmental impact assessment for the facility is excellent, showing no negative impacts arising from the facility's intended use.

Good (6 points). Environmental impact assessment findings are not ideal, but are good. No negative impacts are identified.

Moderate (4 points). Environmental impact assessment and NEPA documentation identify the location as acceptable, meeting all minimum requirements for compliance.

Poor (2 points). NEPA documentation identifies the site as a poor location for the facility's intended use. It may only be used if specific NEPA conditions are met.

Failed (0 points). Environmental impact assessment and NEPA documentation indicate that the site cannot achieve environmental compliance if used for the facility's intended purpose.

3. *Safety Compliance*

General Criteria (Threshold Value: 4)

Excellent (8 points). Safety coordination shows that the location is completely suitable for the facility, and is in compliance with all applicable safety regulations.

Good (6 points). Safety coordination shows that the location meets all minimum safety standards that are applicable.

Moderate (4 points). The location of the facility is acceptable. It may have a few negative features, but OSHA* permits can be obtained.

Poor (2 points). The location has some significant safety problems. OSHA permits can be obtained for conditional use only.

Failed (0 points). The location cannot meet OSHA safety standards even for conditional use, and is therefore completely unacceptable for the facility's intended mission.

*OSHA: Occupational Safety and Health Administration.

4. Impact on ACOE

General Criteria (Threshold Value: 4)

Excellent (8 points). This location is ideal from the ACOE viewpoint. All features are positive and no negative impacts are identified.

Good (6 points). The location has some positive features and no negative impacts.

Moderate (4 points). The location is acceptable from the ACOE viewpoint, but there may be a few negative impacts.

Poor (2 points). The location has many negative features, and would not be completely acceptable according to ACOE criteria.

Failed (0 points). The location is completely unacceptable from the ACOE viewpoint.

5. Transportation Suitability

General Criteria (Threshold Value: 6)

Excellent (8 points). All transportation needs for the facility are met, and the transportation facilities are in good shape.

Good (6 points). All transportation needs are met, and the transportation facilities are in acceptable condition.

Moderate (4 points). Transportation facilities are available, but some repair work may be necessary.

Poor (2 points). Transportation facilities are not completely suitable. Additional roads or major repairs are necessary to bring them up to acceptable standards.

Failed (0 points). Not all necessary transportation facilities are available. Major transportation problems would interfere with support of the facility's mission.

6. Suitability of Utilities

General Criteria (Threshold Value: 4)

Good (6 points). All utilities necessary for the facility's intended mission are available.

Moderate (4 points). The necessary utilities are available, but some minor problems must be addressed.

Poor (2 points). There are significant utility-access problems.

Failed (0 points). Adequate utilities are not available to support the facility's intended mission.

7. *Efficiency of Operations*

General Criteria (Threshold Value: 4)

Excellent (8 points). The location is highly convenient for effective use of the facility.

Good (6 points). The location is reasonably good for convenience and efficiency of operations.

Moderate (4 points). The location supports the facility mission with only a minimal level of inconvenience and operational problems.

Poor (2 points). The location will create major inconveniences and loss of productivity.

Failed (0 points). The location will not support the facility's mission or operational efficiency.

5 RENMOD: A RENOVATION DECISION-SUPPORT MODEL

The main difficulty in deciding whether a facility should be renovated is the decisionmaker's subjectivity. A subjective decision is difficult to justify quantitatively. Furthermore, a subjective decision defies standardization: it varies among decisionmakers and locations. A computerized model cannot eliminate subjectivity, but it can support the renovation decisionmaking process in several important ways.

First, it can break down the overall "renew or not renew" decision into smaller components so the decisionmaker faces simpler questions to deal with subjectively. The model can then integrate the responses to simpler questions, to support a rational decision.

Second, a model can detect inconsistencies in the decisionmaker's answers to the simple questions, and reconcile them to the decisionmaker's satisfaction.

Third, a model can quickly perform computations, such as a sensitivity analysis, to indicate the relative significance of each component of the problem. This capability makes it easier to conduct "what if" analyses.

Fourth, a well designed model is essentially portable from one location to another. Furthermore, if the model's results are not sensitive to the variations in the input, then consistency can be maintained when the model is used by different people at different locations.

Previous Work

A literature search was conducted to identify the theories and methods used for evaluating the facility performance. Two models were found.

One was used in a housing development project in Boston (Schodek 1973):

$$PI_v = \sum_{i=1}^{n} (PI_{pci})(RI_{ci}) \quad \text{[Eq 1]}$$

where:

- v = general evaluation viewpoint, which is helpful in describing the general characteristic attribute of a building (e.g., safety, thermal comfort, serviceability)
- PI = performance indicator, a numerical value
- pci = performance index of building component i, which quantifies the relative adequacy of the component compared to the specified standard for a particular attribute (e.g., the pci for a floor judged 80 percent adequate in terms of stain-resistance would be 0.8)
- RI_{ci} = relative importance of building component i in terms of the evaluation viewpoint; the sum of all RI_{ci} values for a particular evaluation viewpoint totals 1.00.

A second model was developed in Hungary for social housing projects (Visy, May 1983). Building performance was defined as "the behavior of a building, or a component of a building, related to its intended use." The Hungarian model was given as:

$$P = \sum_{i=1}^{M} v_i \frac{B_i}{R_i} \qquad \text{[Eq 2]}$$

where:

M = number of characteristic properties

υ_i = a weighting coefficient denoting the significance of characteristic i, which is determined by the subjective judgments of experts; it is desirable that $\upsilon_i = 1$

B_i = building performance in terms of characteristic i, which can be quantified by a unit of measure, a point, or a binary yes-no (1 or 0) value judgment

R_i = the desired minimum standard of building performance in terms of characteristic i.

In the Hungarian model, it is possible that $\frac{B_i}{R_i} > 1$, which means that current building performance for that characteristic exceeds the minimum requirement.

Both models use essentially the same elements: building characteristics (attributes) are evaluated and assigned a numerical score; the scores are then multiplied by a weighting factor that signifies the relative importance of each attribute; then finally, the weighted scores of each attribute are summed to obtain an overall condition or performance index.

This type of model is called an *additive model*. The major shortcoming of additive models is that they assume that oversatisfaction of one characteristic can compensate for undersatisfaction of another. To illustrate this point, let $M = 2$, $v_1 = 0.5$, $v_2 = 0.5$, $B_1 = 10$, $R_1 = 5$, $B_2 = 0$, $R_2 = 10$, which yields $P = 0.5\ (10/5) + 0.5\ (0/10) = 1$. Although the building performance for the second characteristic (B_2) is completely unacceptable, the building appears to achieve the overall desired level of performance. Additive models have potential applications to M&R scheduling, but reports describing these applications are not available in English.

RENMOD

An additive model, called RENMOD, was developed in this study. To overcome the shortcoming of additive models discussed above, the computer implementation of RENMOD (see Chapter 5) alerts users if a component scores very low.

In general, the proposed model for computing the functional condition index (FCI) of a facility with n components or features takes the following form:

$$FCI = \sum_{i=1}^{n} W(i)X(i) \qquad \text{[Eq 3]}$$

where X(i) is the condition of component i, and W(i) is the relative importance (weight) of that component within the overall functional condition. For some components, X(i) can be directly assessed by inspecting the building. For others, X(i) is computed with a similar additive formula:

$$X(i) = \sum_{k=1}^{K} W_k(i)X_k(i) \qquad \text{[Eq 4]}$$

where $X_k(i)$ is the condition of subcomponent k of component i, and $W_k(1)$ is its relative importance in terms of component i. Similarly, for some subcomponents, $X_k(i)$ can be directly measured or assessed, while for others it is computed by:

$$x_k(i) = \sum_{l=1}^{L} W_k^l(i)x_k^l(i) \qquad \text{[Eq 5]}$$

where $x_k^l(i)$ is the condition of the lowest-level component, and $W_k^l(i)$ is its relative importance in terms of subcomponent k.

Therefore, RENMOD is hierarchical. Model construction starts from the lowest level and is built upwards. The following section describes the application of this model to administrative buildings. Methods for computing the weights are discussed later in this chapter.

Building the Model for Administrative Buildings

An administrative building is assumed to comprise 16 of the 17 main components discussed in Chapters 3 and 4:

1. Functional spaces (X(1), W(1))
2. Supporting spaces (X(2), W(2))
3. Ceiling height (X(3),W(3))
4. Access to material and equipment (X(4), W(4))
5. Handicap access (X(5), W(5))
6. Floors (X(6), W(6))
7. Health and safety (X(7), W(7))
8. Grounds (X(8), W(8))
9. Sound and visual environment (X(9), W(9))
10. Electrical service and fixtures (X(10), W(10))
11. Water and Plumbing (X(11), W(11))
12. HVAC (X(12), W(12))
13. Security (X(13), W(13)

14. Communications ($X(14)$, $W(14)$)
15. Environmental impact ($X(15)$, $W(15)$)
16. Aesthetics and image ($X(16)$, $W(16)$)

Note that this example does not address the built-in equipment attribute. Administrative facilities generally do not require the kind of built-in equipment evaluated under this attribute.

Each of these is explained below. The terms in parentheses after each attribute represent the model's designation for the component and its weighting scale. Application of the model to each attribute is explained in the following sections.

Functional Spaces

Suitability of functional spaces is not directly assessed, but is computed in terms of its components using the following sequence of operations.

First, through inspection of the building, directly assess:

- Dimensions of functional spaces (denoted by $x_1(1)$)
- Layout of functional spaces (denoted by $x_2(1)$).

These two component features determine the suitability of functional spaces.

Assume that the relative weights of these two component features are $w_1(1)$ and $w_2(1)$ (computation of the weights is discussed in the next section). Then, the suitability of functional spaces ($X(1)$) is calculated as follows:

$$X(1) = w_1(1)\, x_1(1) + w_2(1)\, x_2(1)$$

Supporting Spaces

Supporting spaces have two components that are assessed directly by the inspection:

- Supporting spaces (quantitative) ($x_1(2)$, weight: $w_1(2)$)
- Layout of supporting spaces ($x_2(2)$, weight: $w_2(2)$).

Then compute the suitability of supporting spaces ($X(2)$) as follows:

$$X(2) = w_1(2)\, x_1(2) + w_2(2)\, x_2(2)$$

Ceiling Height

Ceiling height ($X(3)$) is assessed directly by inspection. Because there are no subcomponents to this attribute, the rating is simply the product of its basic suitability and its weighting factor.

Access to Material and Equipment

The two components of this attribute are directly assessed:

- Width and height of doors ($x_1(4)$, weight: $w_1(4)$)
- Circulation (corridor width etc.) ($x_2(4)$, weight: $w_2(4)$).

Compute the adequacy of the supporting spaces ($X(4)$) as follows:

$$X(4) = w_1(4)\ x_1(4) + w_2(4)\ x_2(4)$$

Handicap Access

Handicap access ($X(5)$) is directly assessed. The result of this assessment, multiplied by its weighting factor.

Floors

Floors are rated on the basis of two components:

- Floor loads ($x_1(6)$, weight: $w_1(6)$)
- Floor finishes ($x_2(6)$, weight: $w_2(6)$).

Compute the condition of the floors ($X(6)$) as follows:

$$X(6) = w_1(6)\ x_1(6) + w_2(6)\ x_2(6)$$

Health and Safety

This attribute has three subcomponents, each of which is assessed directly through inspection:

- Fire safety ($x_1(7)$, $w_1(7)$)
- Health risks (asbestos, fumes, smoke, radon, etc.) ($x_2(7)$, $w_2(7)$)
- Operational safety ($x_3(7)$, $w_3(7)$).

The health and safety condition of the building is computed as follows:

$$X(7) = w_1(7)\ x_1(7) + w_2(7)\ x_2(7) + w_3(7)\ x_3(7)$$

Grounds

Grounds has three subcomponents, each of which has to be assessed directly through inspection:

- Parking ($x_1(8)$, $w_1(8)$)
- Vehicular access ($x_2(8)$, $w_2(8)$)
- Landscaping ($x_3(8)$, $w_3(8)$).

The condition of grounds $X(8)$ can then be computed as follows:

$$X(8) = w_1(8)\ x_1(8) + w_2(8)\ x_2(8) + w_3(8)\ x_3(8)$$

Sound and Visual Environment

This attribute has two subcomponents, both of which have to be assessed directly through inspection:

- Acoustics ($x_1(9)$, $w_1(9)$)
- Visual environment and glare ($x_2(9)$, $w_2(9)$).

The rating for this attribute can then be computed as follows:

$$X(9) = w_1(9)\ x_1(9) + w_2(9)\ x_2(9)$$

Electrical Service and Fixtures

The electrical system includes three subcomponents, each of which has to be assessed directly through inspection:

- Building power supply ($x_1(10)$, $w_1(10)$)
- Power distribution ($x_2(10)$, $w_2(10)$)
- Adequacy of fixtures ($x_3(10)$, $w_3(10)$).

The rating for this attribute is then computed as follows:

$$X(10) = w_1(10)\ x_1(10) + w_2(10)\ x_2(10) + w_3(10)\ x_3(10)$$

Water and Plumbing

This attribute has two subcomponents, each of which is assessed directly through inspection:

- Water supply ($x_1(11)$, $w_1(11)$)
- Plumbing system ($x_2(11)$, $w_2(11)$).

The condition rating for this attribute is computed as follows:

$$X(11) = w_1(11)\ x_1(11) + w_2(11)\ x_2(11)$$

HVAC

The HVAC system has two subcomponents, which are assessed directly through inspection:

- Temperature and humidity ($x_1(12)$, $w_1(12)$)
- Ventilation ($x_2(12)$, $w_2(12)$).

HVAC suitability of the building is then computed as follows:

$$X(12) = w_1(12)\ x_1(12) + w_2(12)\ x_2(12)$$

Security, Communications, and Environmental Impact

These three components (denoted, respectively, by X(13), X(14), and X(15); weight W(13), W(14), and (W15)) do not have subcomponents. Each is assessed directly through inspection, and suitability is computed by multiplying the result of the assessment by the weighting factor.

Aesthetics and Image

This attribute is divided into three components, each of which is assessed directly through inspection:

- Exterior appearance ($x_1(16)$, $w_1(16)$)
- Appearance of public spaces ($x_2(16)$, $w_2(16)$)
- Appearance of interior spaces ($x_3(16)$, $w_3(16)$).

The rating for this attribute can then be computed as follows:

$$X(16) = w_1(16)\, x_1(16) + w_2(16)\, x_2(16) + w_3(16)\, x_3(16)$$

Calculating the Functional Condition Index

After the condition indexes for all building attributes are computed, the overall functional condition index (FCI) is computed as follows:

$$\begin{aligned} FCI_{ab} = {} & W(1)X(1) + W(2)X(2) + W(3)X(3) + W(4)X(4) + W(5)X(5) + W(6)X(6) + \\ & W(7)X(7) + W(8)X(8) + W(9)X(9) + W(10)X(10) + W(11)X(11) + W(12)X(12) + \\ & W(13)X(13) + W(14)X(14) + W(15)X(15) + W(16)X(16) \end{aligned}$$

The resulting number, FCI_{ab}, represents an overall measure of the functional condition of the administrative building.

Weighting the Attributes

There are a number of methods for weighting the attributes in the model presented above. A detailed review of these methods is given in Appendix A, including a discussion of the advantages and disadvantages of each method. Two methods that seem particularly applicable to the objective of this research are explained below.

The reader should note that the discussion of weighting here and in Appendix A uses examples based on the original version of the building attribute tree, as explained in Chapter 1 under "Approach" (see Figure 1). The difference in criteria does not affect the applicability of the weighting methods to RENMOD.

Ratio Method

First, a given set of attributes is ranked in order of their relative importance. The least important attribute is assigned a weight of 10. The weights of all other attributes are then rated as multiples of 10, depending on their relative importance to the least important one. For example, the attribute ***building layout suitability*** has seven subattributes. Suppose the least important subattribute is ***ceiling height***, which is weighted at 10. Suppose the subattribute ***floors*** is a little more important, but not twice as important, then this subattribute could be assigned a weight of 15. If functional space layout and suitability is the most important one—perhaps 10 times more important than the ceiling height—then a weight of 100 is assigned.

Weights determined in this fashion are called *raw scores*. They express the relative importance of the attributes. In the computations, the raw scores are normalized so their sum equals 1.

Analytical Hierarchy Process

Analytical hierarchy process (AHP) (Saaty 1980) involves comparison of two attributes at a time. The relative importance of one to the other one is often expressed in narrative terms, then Table 1 is used to convert these descriptions into numerical values. Creating an example from the administrative building attributes discussed previously, suppose *floors* is only slightly more important than *ceiling height*. In the AHP evaluation matrix (Table A1), at the intersection of the *floors* row and *ceiling height* column there is 2. Furthermore, at the intersection of the *functional space layout and suitability* row and *ceiling height* column, there is an 8, meaning the former heavily outweighs the latter in importance. After comparisons are completed between all pairs of attributes, the weights for each attribute can be computed using the formulas presented in Appendix A.

From the two comparisons in the example above, one could compute the relative importance of the two attributes. However, this number is requested from the decisionmaker to serve as redundant information that can be used to check the consistency of the responses. (See supporting text at Table A1.) This method provides a way to compute the level of inconsistency, which up to a certain extent is acceptable—and almost inevitable. However, if the inconsistency level is too high, then the question session with the decisionmaker is started again to identify the source of inconsistency and eliminate it.

Choosing a Method

Both weighting methods described here require subjective input from the decisionmaker on the relative importance of each attribute and subattribute to overall functional condition. There are three important criteria for determining which method to use:

<u>Ease of Use</u>. In the administrative building, for example, there are 48 attributes and subattributes. The time spent to determine the relative importance of each attribute is well worth the effort, especially because it is done once, then revised only as needed. Nevertheless, it is a demanding task, and the chance of making errors or creating inconsistencies increases as the number of judgments required increases. Therefore, it is important that the method is easy to use.

<u>Trusthworthiness</u>. The weighting method should be transparent, rather than an opaque system. The user should be able to understand and have confidence in the results. When subjective inputs are concerned, this criterion is particularly important.

<u>Robustness</u>. If the results of the proposed method are very sensitive to small changes in the inputs, then the reliability and general value of the model decrease. Because the proposed model requires subjective inputs, different individuals may provide different numbers. Therefore, the robustness of the weighting scheme is very important.

These two weighting methods were presented to a group of planners from Army installations. This group favored the AHP, and provided the necessary inputs for determining the weights of attributes both for an administration building and a warehouse. The results of this session are summarized in Appendix B.

Table 1

Numerical Values for Relative Importance of Attributes

Intensity of Importance	Definition	Explanation
1	Equal importance of both elements.	Two elements contribute equally to the property.
3	Weak importance of one element over another.	Experience and judgement slightly favor one element over another.
5	Essential or strong importance of one element over another.	Experience and judgement strongly favor one element over another.
7	Demonstrated importance of one element over another.	An element is strongly favored and its dominance is demonstrated in practice.
9	Absolute importance of one element over another.	The evidence favoring one element over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between two adjacent judgements.	Compromise is needed between two judgements.
Reciprocals	If activity i has one of the preceding numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

The installation planners strongly endorsed AHP in terms of ease of use and trustworthiness. To investigate the method's robustness, it was analyzed against the complete model, outlined earlier in this chapter. The model requires two types of inputs: a rating for a functional attribute (denoted by x in the model) and a value for the weight (relative importance) of each functional attribute (denoted by w in the model). Both types of input may vary from person to person and location to location, even if the facility being assessed is the same. To check whether such variance affects the final output—FCI of the facility under consideration—a set of Monte Carlo (general simulation) runs was performed. In each run, the score values (x) and weights (w) varied randomly. The results, summarized in Appendix C, show that the output of the model is quite robust against changes in inputs. This result has already been demonstrated to be generally true for linear additive models (Dawes 1979).

Summary of RENMOD

RENMOD is essentially a model for measuring a facility's functional condition. Almost any nontrivial measurement in engineering, science, or management may be subjective, inaccurate, and potentially misleading. Computers and models cannot eliminate the subjectivity, but they can help make potential errors more conspicuous, and provide a means to correct them. Subjective human input into building renovation decisions is essential and cannot be replaced. It can, however, be supported or enhanced. RENMOD appears to be capable of reliable renovation decision support.

The model can be used to determine a facility's FCI. This index could be used in two ways. If a number of facilities are available, the FCI could be used to rank the comparative functional conditions of each. If only one facility is being considered, and the issue is whether to renovate it or not, then the FCI can indicate whether to renovate, not to renovate, or an unclear situation. If the case is unclear for a single facility, the model's output would suggest that a closer look by decisionmakers is required.

6 COMPUTER IMPLEMENTATION OF RENMOD

Overview of Prototype System

RENMOD has been automated as an application for desktop computer. The foundation of the microcomputer application is the value tree shown in Figure 1 (Chapter 1). All features of the model—the value tree, its structure, attributes, attribute weights, and evaluation scales—are built into this system. The user interface and system operations are designed so the user does not need to understand the model's inner workings to evaluate a facility's FCI. However, familiarity with the meaning of each attribute may increase the accuracy of the user's judgment.

Description of a Working Session

A working session with the computerized system consists mainly in choosing a value from qualitative scales developed for each attribute. The system guides the user through attribute-evaluation menus. In the prototype version, the order of attribute evaluation is set by the system, so the user does not control this aspect of the evaluation. Detailed descriptions for each qualitative value on the scales are provided as an online help feature.

An example of the screen for evaluating the availability of functional spaces is shown in Figure 5. All other opened windows are shown bordered in bold lines. The names of attributes are in the upper-left corner of each window. For example, the terminating (most detailed) attribute currently under evaluation in the figure is in the lowest screen, where the multiple qualitative choices are located. Windows are

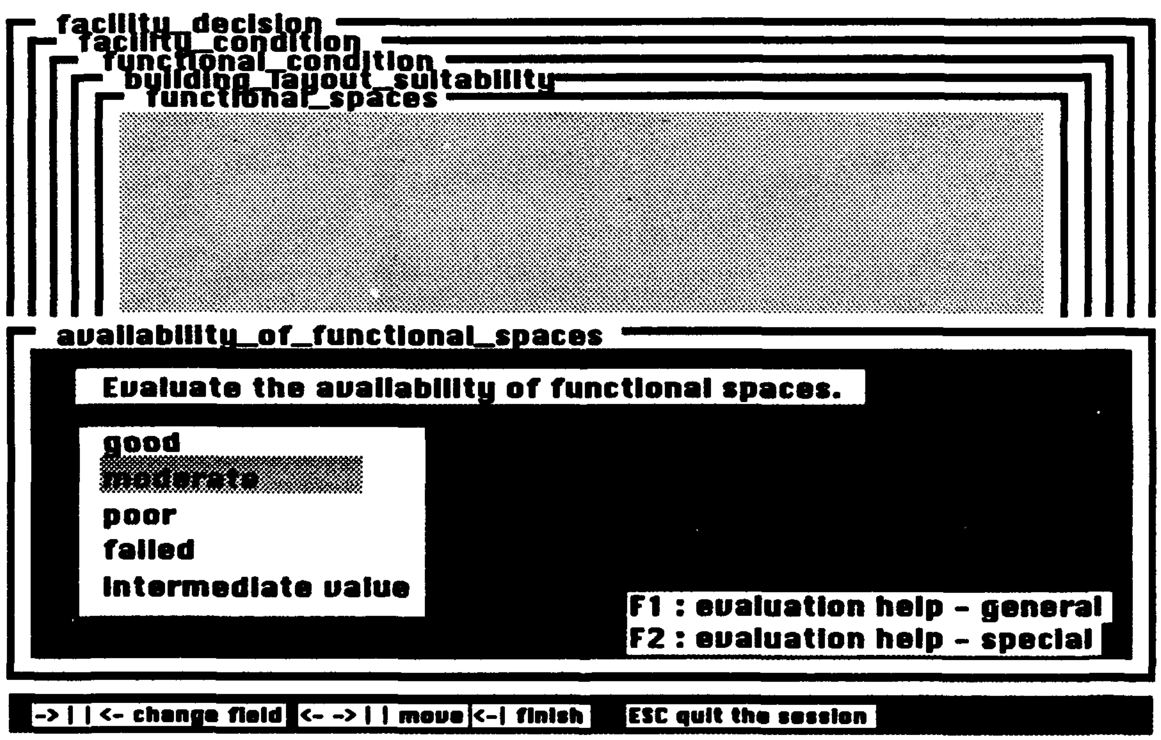

Figure 5. Evaluation Screen.

layered under the active window in order of the value tree hierarchy, from bottom to top. Thus, *functional spaces* is the next upper-level attribute of *availability of functional spaces*, as is *building layout suitability* for *functional spaces*. The evaluation task appears above the qualitative choices. The current highlighted value (*moderate* in Figure 5) will be chosen if RETURN is pressed. The selection bar is moved by using the keyboard's arrow keys. Other evaluation screens highlight a different evaluation task, and may have a different number of qualitative choices. In the lower right corner of the evaluation screen there is a reminder of how to activate the help function (by pressing F1 or F2). There are two versions of the help function: one for general evaluations and one for special-purpose evaluations. Figure 6 shows the screen with opened help window.

As the user evaluates the condition of each attribute, the qualitative values selected (excellent, good, moderate, poor, failed, or any value in between) are being converted to their corresponding numerical values and divided by the maximum possible value for the particular attribute, to obtain a relative value for the attribute score. When all components of an attribute are evaluated, the system takes the score, multiplies it by the decisionmaker's specified weights (input previously), and aggregates them to compute a relative rating for the condition of the upper-level attribute. The system then moves to the next upper-level attribute according to the preset sequence, through the entire value tree. As can be seen, the terminating nodes (e.g., *availability of functional spaces* in Figure 5) in the value tree are the attributes actively being evaluated by the user. The number of evaluation tasks presented to the user corresponds to the number of terminating nodes (leaves) of the value tree.

As the user progresses through the evaluation, the values chosen up to that point are displayed in the windows corresponding to each upper-level attribute in the value tree hierarchy. The values obtained by aggregation of the lower-level attributes are also displayed. Figure 7 shows a screen where no

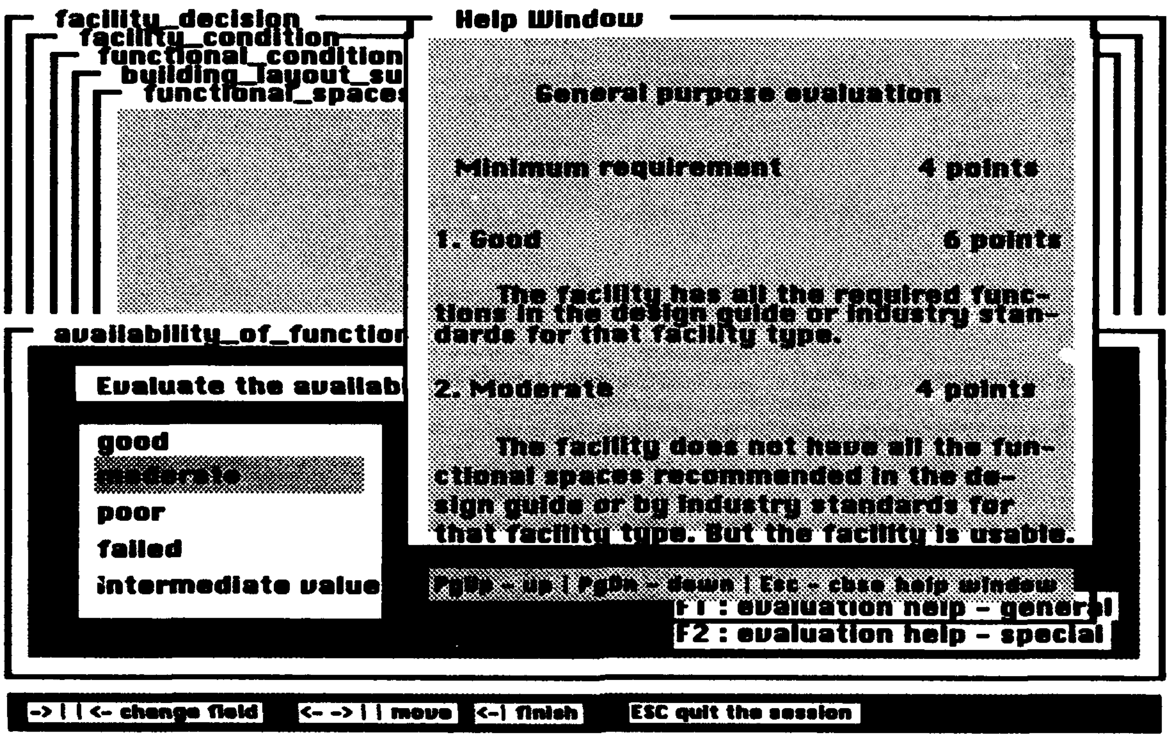

Figure 6. Help Screen.

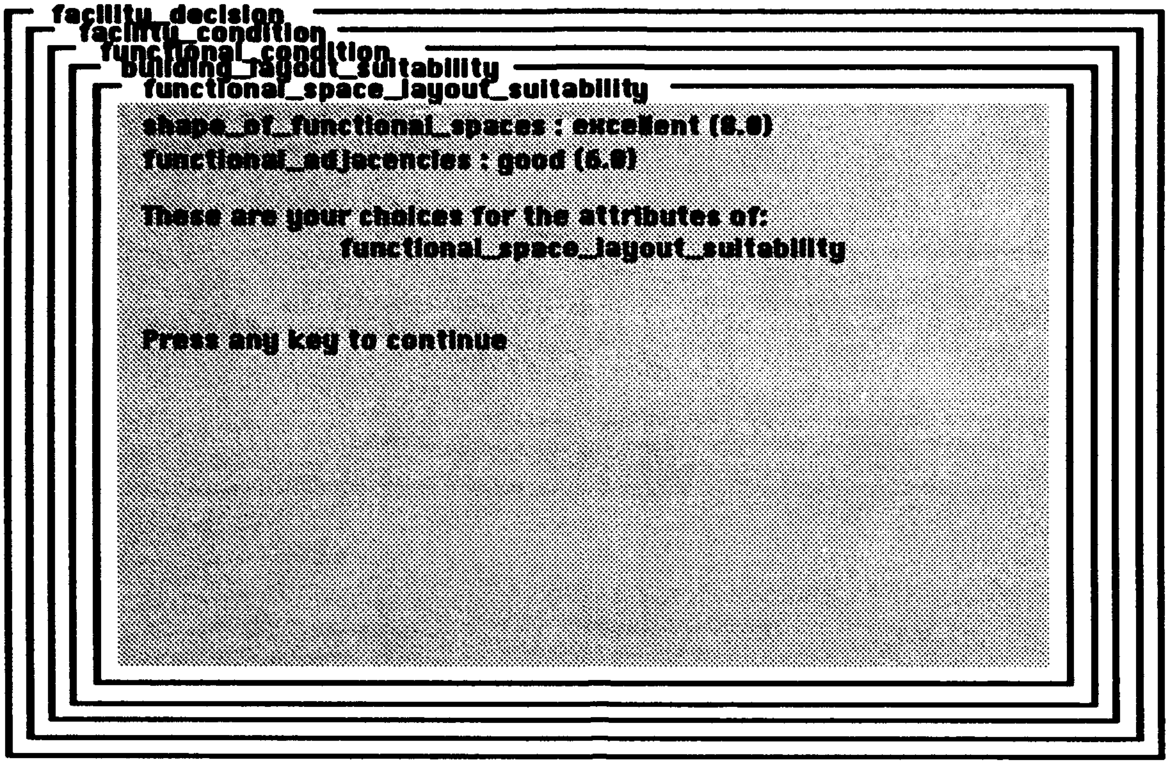

Figure 7. Screen Showing Evaluated Attributes.

evaluation window is active. The evaluation information is displayed only when all terminating attributes for the upper-level attribute are evaluated.

When the evaluation for all terminating attributes is completed, a single relative score—the FCI—is computed. The screen in Figure 8 shows the scores for all subattributes of functional condition. The attribute ratings that show a qualitative term before the numerical score (e.g., good, moderate) are attributes without any subattributes or subcomponents.

After any key is pressed, a new window appears on the screen with an evaluation recommendation statement for overall functional condition (Figure 9). This recommendation is based on comparison of the score obtained during the session to an overall facility threshold value. This overall value is computed from the values for a hypothetical facility for which the scores of all terminating attributes and subattributes correspond to the minimum requirement—*moderate* in most of the cases. See the example in the light gray box in the foreground of Figure 6.

The recommendation statement for functional condition appears in a menu that allows the user to move on to evaluation of the building's physical condition, or to rate the facility only on the basis of functional condition. If the user chooses to evaluate the building's physical condition, the overall facility condition score is computed by aggregating the scores obtained for functional and physical condition. In the prototype system, it is assumed that evaluation of physical condition has been done independently and that the results are supplied in the system database. The physical condition scores are read from the database and used to compute the overall score for facility condition.

A sample condition evaluation report printed from the computer implementation of RENMOD is provided in Appendix D.

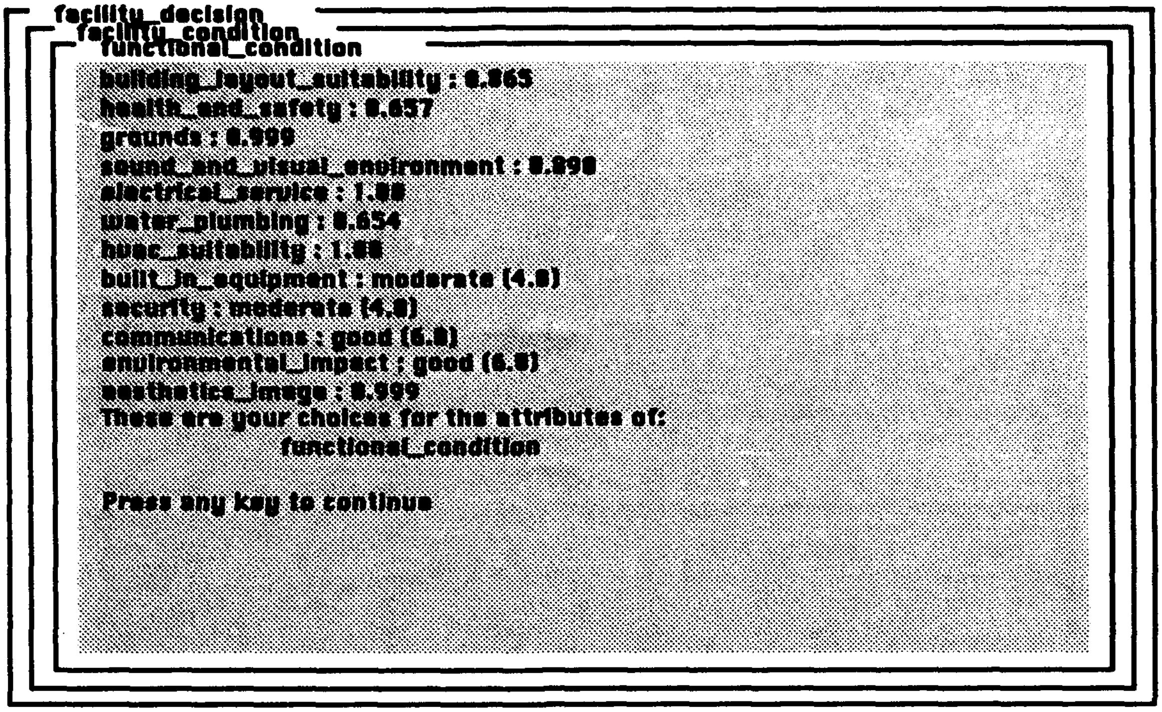

Figure 8. Functional Condition Screen.

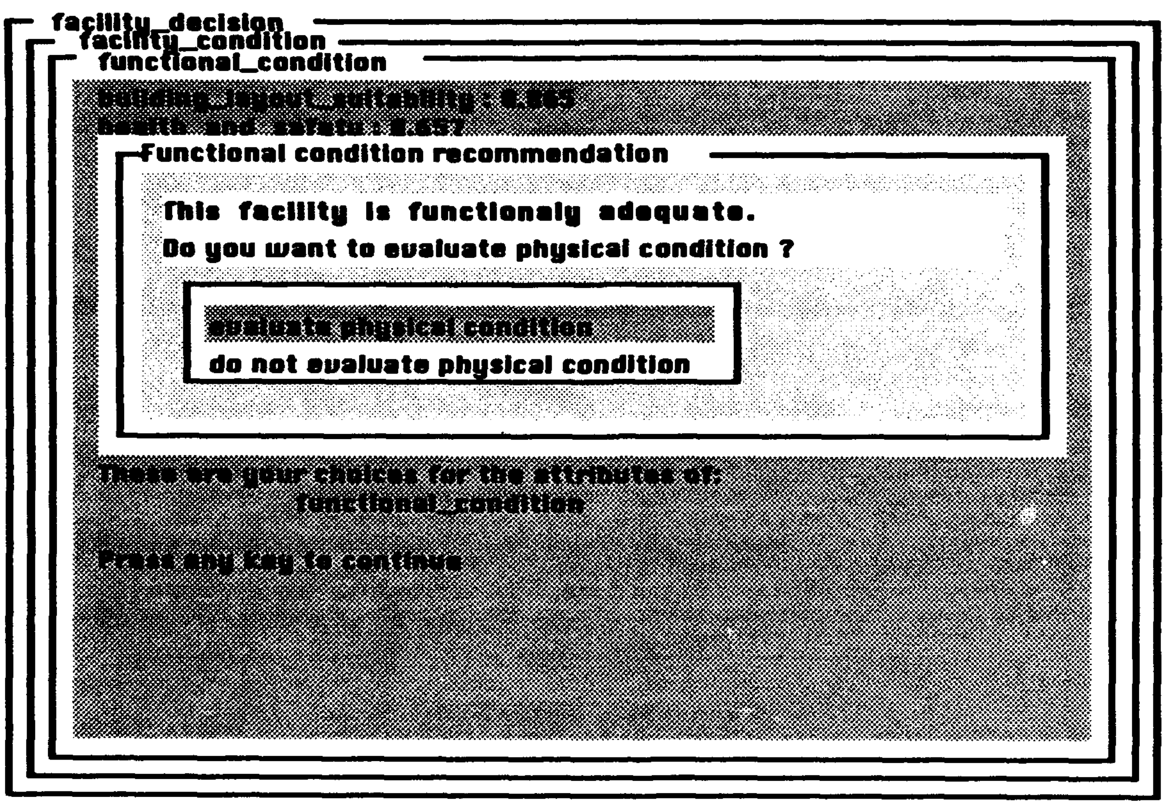

Figure 9. Evaluation Recommendation Screen.

Architecture of the System

The architecture of the renovation decision support system is shown in Figure 10. Its main parts are:

- Working memory
- User interface
- Knowledge base
- Control module.

Working memory is an internal object-level database where a dynamic updating of system computations takes place. The partial result of a computation can exist in working memory at any moment. Each node from the value tree hierarchy has a corresponding object in the internal database. The object carries all necessary information about the value tree node (e.g., its supernode in the hierarchy, the number of its subnodes, type of entry needed from the user). As the user proceeds through the value tree hierarchy, an object is generated in working memory for each new node. The object stays in the working memory as long as its information is needed for computing the index for the subhierarchy of its supernode. When the index of its supernode is computed, the object is removed from working memory.

The knowledge base contains the frame-based internal representation of the value tree. Each node in the value tree hierarchy is represented by one frame that contains all static data needed during system operation. These data include name of the node, type of node (terminal or goal node), number of subnodes (if goal node), names of subnodes, name of the supernode, type of entry needed from user, weight, etc. Most of this information is passed to the objects generated for each node in working memory.

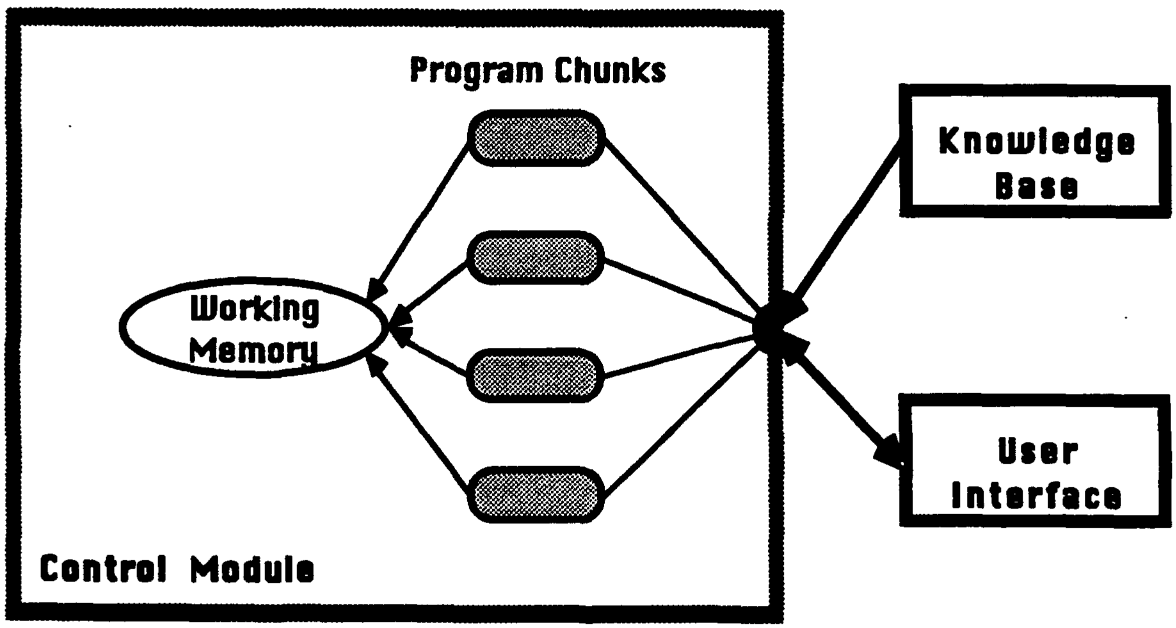

Figure 10. General System Architecture.

The user interface consists of menu-generating programs that create the needed type of menu for different objects in working memory. The user interface is activated every time the control module delegates a program chunk that activates the user interface.

The control module oversees all other system modules and coordinates their activities. It is organized into independent program chunks that operate on the objects in working memory, connect the working memory with the user interface when needed, obtain the information from the knowledge base when an object in working memory is created or updated, etc. The control module coordinates these program chunks by deciding which will operate next. When there is a conflict between two program chunks, the control module consults its own small knowledge base, which contains information on how to resolve the conflicts. Other parts of the control module are the working memory maintenance module and the interrupt handler. The working memory maintenance module purges working memory at the end of a session. The interrupt handler is activated when the user requests help, for example—any action affecting system operation which cannot entirely be predicted.

The prototype of the renovation decision support system was written in PROLOG, and requires a 386-based DOS*-compatible microcomputer.

*DOS: Disk Operating System.

7 CONCLUSION

Building renovation is an important alternative to consider in the real-property master planning process. Renovation may be highly cost-effective or may present serious problems, depending on the facility's condition and its ability to fulfill its intended mission. While some quantitative approaches exist for measuring the value of a building investment, qualitative factors generally determine the major part of the investment decision. Although some qualitative benefits can be quantified in monetary terms, it is not possible or practical to quantify many qualitative benefits (e.g., convenience, quality of life, safety, etc.) in monetary terms.

To address the need for reliably determining a facility's functional condition, USACERL developed a comprehensive set of attributes to more objectively measure the functionality of a facility. Because most of the attributes are rated subjectively, an index was constructed to quantify these attributes. Rating scales and their definitions were developed, and a standard minimum level of functional condition—the threshold value—was defined for each attribute. Because not all attributes are of equal importance for a given facility, procedures for weighting the attribute values were evaluated and incorporated. The elements of the system were presented to a group of experts in the field for comment and input. The result of the work was a renovation decision-support tool called RENMOD.

The attributes and rating procedure can be applied to facilities despite differences in age, facility type, construction type, or configuration. The attributes are not affected by the changes in the standards or complexity of requirements. This classification system can be used by any person with enough knowledge to identify facility features and understand plain-language criteria.

Special professional expertise (e.g., registration as an architect or engineer) is not required for assessment of most functional condition attributes, but familiarity with Army regulations, standard design features, and design guides will help the inspector. Knowledge of the criteria *is* required, however. And it is important to note that professional expertise *is* required to inspect and evaluate health and safety features, engineering systems, security, and communications.

USACERL implemented RENMOD on a microcomputer to provide automated decision support for functional condition assessments. The user inputs facility information, and the computer calculates a functional condition index (FCI) for the facility. This index can help the facility planner or manager determine the need for renovation.

The assessment and rating process described in this report can be applied to determining the suitability of a facility's location as well as its functional suitability. The process can also be used to compare the functionality of alternative facilities.

Because the model on which this process is based can weight attributes differently to adapt to different facility types or user requirements, the approach described here appears to be a very practical general tool to evaluate facility condition.

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APPENDIX A: Methods for Determining Weights*

To quantify the importance of an attribute to the functional condition of a facility, a weighting factor must be formulated. Various weighting schemes are used in practice, and the model presented in this report can be used with any of them—although some are more appropriate than others. This appendix presents relevant weighting schemes and provides a detailed description of the Analytical Hierarchy Process (AHP), the method this study recommends. Although AHP seems to be the most advantageous weighting scheme, different situations may require different weighting schemes. Furthermore, it is often advisable to use more than one weighting method to eliminate potential inconsistencies.

Weighting Schemes

In the following examples of weighting, the original attribute structure is used in which the *building layout suitability* component of the functional condition consists of seven subcomponents:

1. Functional spaces (FS)
2. Functional space layout suitability (FSLS)
3. Supporting spaces (SS)
4. Ceiling height (CH)
5. Access to material and equipment (AME)
6. Handicap access (HA)
7. Floors (F).

Ratio Method

First, the decisionmaker is asked to rank order the 7 attributes. Suppose the order (from most important to the least) is as follows:

1. FS
2. FSLS and SS
3. AME
4. HA
5. CH and F.

Note that FSLS and SS are perceived to be equally important, so are CH and F. Next, the least important attribute (in this case both CH and F) is given the weight of 10. Then, the decisionmaker is asked the strength of importance of the next attribute from the bottom, relative to the least important one. In this case, suppose the decisionmaker expressed that HA is twice as important as CH and F. Then the weight of HA is 20. Next, the decisionmaker found AME three times more important than CH and F, so AME's weight is 30. The other values are set the same way. Suppose the resulting raw weights are:

FS	80
FSLS	50
SS	50
AME	30

* This part of the research was conducted using the original attribute tree, as presented in Figure 1 (Chapter 1). Although the attribute tree was later refined and modified (Figure 2), the assumptions and logic of this discussion pertain to the new tree as well as the old.

HA	20
CH	10
F	10

To normalize these raw weights, divide each by the sum of all weights. The result is the set of weights required:

FS	0.32
FSLS	0.20
SS	0.20
AME	0.12
HA	0.08
CH	0.04
F	0.04

The sum of these normalized weights is 1.00, so each weight can be treated as fraction or as percentage. For example, based upon the above results, one may more easily see that 20 percent of the building layout suitability depends on the condition of the supporting spaces (in this example).

The ratio method is simple and widely used. One drawback is that it does not consider the range of possibilities for an attribute. For example, cost may generally be the most important attribute for a person evaluating cars to purchase. However, consider a person living in a small town with only one auto dealership, where the prices of all cars are very similar. In such a case, other attributes tend to become more important than price because, within the conditions of the specific example, price is by definition no longer the most important attribute. In cases where the range of possible values for an attribute is narrow, the ratio method is not a good one to employ. In fact, only the *swing method*, described below, considers the range of scores that can be assigned to attributes.

Point Allocation

In this direct-elicitation method, the decisionmaker is asked the following question: Suppose you have 100 points, how would you distribute them over the attributes. The distribution reflects the relative importance of the attributes. It can be seen that this is a highly subjective approach; the model's accuracy depends on the expertise of the decisionmaker.

Swing Method

The decisionmaker is asked to imagine a facility with the worst possible value for each attribute. Then the decisionmaker is asked, "If you could *swing* one of the attributes from its lowest level to its best level, which would you choose?"

In the current example, suppose that the decisionmaker chose to swing FS from the worst to the best value, to have the greatest positive effect on building layout suitability. By definition, then, FS would be the most important attribute.

The same question is repeated for the remaining six attributes. The responses provide a priority ranking of the attributes. For the purposes of this example, suppose the result is the same ranking order given in the ratio method example above.

To determine the raw weights, first assign 100 to the most important attribute, which is FS. Then ask, "What percentage of FS is the significance of swinging FSLS (or SS) from the worst to the best possible level?" Suppose the answer is, "The swing in FSLS or in SS is 50 percent as significant as the swing in FS, as far as building layout suitability is concerned." Next, ask the same question for AME, then for HA, and finally for CH or F. Suppose the results are as follows:

FS	100
FSLS	50
SS	50
AME	20
HA	15
CH	5
F	5

To normalize these raw weights, divide each by the sum of all weights. The result is the set of weights required:

FS	0.408
FSLS	0.204
SS	0.204
AME	0.082
HA	0.061
CH	0.020
F	0.020

The sum of these normalized weights is 1.00. Therefore, each weight can be treated as fraction or percentage. For example, based upon the above results, it is easy for the user to see that 20.4 percent of building layout suitability depends on the condition of the supporting spaces.

Rank Sum Weight

This method requires only the rank ordering of alternatives. The degree of importance of each attribute is not elicited. Instead, the weights are computed using the following formula:

$$W_i = \frac{N - R_i + 1}{\sum_{j=1}^{N} (N - R_j + 1)} \qquad \text{[Eq A1]}$$

where W_i is the normalized weight for attribute i
N is the number of attributes (seven in this case)
R_i is the rank order (position) of attribute i.

For instance, in the above case, consider attribute 2—FSLS. Its rank is 2, so its weight is computed as follows:

$$W_2 = (7-2+1)/[(7-1+1)+(7-2+1)+(7-2+1)+(7-3+1)+(7-4+1)+(7-5+1)+(7-5+1)]$$

which yields $W_2 = 0.1764$. This method yields the following weights for the seven attributes.

FS	0.206 (0.233)
FSLS	0.177 (0.200)
SS	0.177 (0.200)
AME	0.147 (0.133)
HA	0.117 (0.100)
CH	0.088(0.067)
F	0.088(0.067)

Note that in the above computations, FSLS and SS both rank second. The question is whether the next attribute, AME, should rank third or fourth? In the above computation, AME was assumed to rank third. The numbers in parentheses give the weights if it is assumed that AME ranks fourth, HA ranks fifth, and CH and F tie at sixth.

Rank Exponent Weights

Similar to the foregoing method, this method requires o..ly a rank ordering of the attributes. The formula for computing the weights is:

$$W_i = \frac{1/R_i}{\sum_{j=1}^{N} (1/R_j)} \qquad \text{[Eq A2]}$$

where W_i, R_i, and N are defined as in Equation A1, and computations are done as above.

Analytical Hierarchy Process

AHP is based on the comparison of attributes two at a time. Considering the current example and using the scale given in Table A1, fill the matrix by putting 1s in the diagonal positions as indicated. The values in the 21 boxes above and right of the diagonal line of 1s are supplied by the decisionmaker; the values below and left of the 1s are reciprocals of ones supplied by the decisionmaker.

As an example, consider Row 3 in the matrix (SS). To compute the upper-right entries, the decisionmaker is asked, "How important is SS compared to CH?" Suppose the answer is "the same." Put 1 in the cell at Row 3, Column 4. Likewise, because the importance of SS and AME are the same, put 1 in the cell at Row 3, Column 5. Next, the decisionmaker states that SS is one-third more important than HA (conversely, HA has weak importance over SS), so put 1/3 in the cell at Row 3, Column 6. Finally, SS is stated to be strongly more important than F, so put 5 in Row 3, Column 7. Complete the other rows in the same fashion.

This elicitation process collects redundant information, which is used for consistency checks. For example, in Row 3, Columns 4 and 5 have 1s, meaning that the importance of SS is equal to the importance of CH and AME. This implies that CH and AME must have the same importance. However, in the cell at Row 3, Column 4 there is a 3, which means that CH is three times more important than SS (or that CH has a weak importance to AME). Such inconsistencies are inevitable, and are acceptable, as long as they do not exceed a certain limit. AHP provides means for computing a consistency ratio, which indicates whether the results are acceptable or not.

Table A1

AHP Evaluation Matrix

Building Layout Suitability	Functional Spaces	Functional Space Layout Suitability	Supporting Spaces	Ceiling Height	Access to Material and Equipment	Handicap Access	Floors
Functional Spaces	1	1	1/3	1/3	1/3	1	7
Functional Space Layout Suitability	1	1	1/3	3	1	1	5
Supporting Spaces	3	3	1	1	1	1/3	5
Ceiling Height	3	1/3	1	1	3	1/3	5
Access to Material and Equipment	3	1	1	1/3	1	1/3	3
Handicap Access	1	1	3	3	3	1	5
Floors	1/7	1/5	1/5	1/5	1/3	1/5	1

After eliciting the comparisons and constructing the above matrix, weights are determined by the following two operations:

1. Normalize each column by dividing each entry in the column by the sum of all entries in that column

2. Take the average of all entries in each row of the normalized matrix; this determines the weight of the attribute in that row.

The matrix given above yields the following weights:

FS	0.114
FSLS	0.158
SS	0.178
CH	0.157
AME	0.120
HA	0.243
F	0.029

The consistency ratio is 46 percent, which indicates poor consistency. The recommended upper limit for good consistency is 10 percent. The result in this example is suspect.

Choice of a Weighting Scheme

Four criteria are used for the choice and application of a weighting scheme: ease of use, trustworthiness, robustness, and technical validity.

Ease of use and trustworthiness depend upon the context of the problem and the aptitudes of the users. The methods described above were presented to six planners from different Army installations. AHP was chosen. (This result was further verified by participants in the USACERL RENMOD Workshop.)

When using AHP, RENMOD was found to be insensitive to small random variances in judgments about the weights.

The technical validity issue has three components:

Convergent validity. Weights derived by different methods should be compared with each other. Furthermore, the FCI obtained at the end, using the weighted model, is compared with the holistic evaluation. The holistic method does not evaluate each attribute, but the overall functional condition. If the results are close to each other (technically measured by tau-correlation), then the convergent validity is satisfied.

Internal consistency. A given method is used by different individuals, or by the same individual at different times. If the results agree with each other, then internal consistency is satisfied.

External validity. Weights and the FCI are compared to an externally obtained result. For example, benchmark weights could be determined by experts in carefully designed interview sessions. Or, if there is a generally agreed-upon case of facility condition evaluation, the model with the weighted attributes could be used also for the same facility, to see if the model yields the same generally accepted evaluation result.

A number of experimental studies have analyzed the validity of the weighting schemes along these three dimensions (von Winterfeldt and Edwards 1986; Borcherding, Eppel, and von Winterfeldt 1991). These studies did not find one method to be better or worse in any of these validity dimensions. However, in different contexts, one method may perform better than another.

In the absence of general support for one method, the question is which method works best in the context of evaluating facilities. There is no reported study on the application of these weighting schemes to facility condition evaluation.

In the absence of hard research pertaining to weighting schemes for facility evaluation, two rules of thumb may be helpful:

1. The user should feel comfortable with the method, and trust how it works

2. Proper administration of the elicitation procedure, computations, and analysis are immeasurably more important than the specific weighting scheme employed.

APPENDIX B: Application of the Model and Numerical Results

The model developed in this study was tested in two different settings. First, a "knowledgeable individual"—not the decisionmaker but a person qualified to inspect facilities and consider renovation issues—was presented with the model and the weighting schemes. Second, six planners from different installations were presented the weighting schemes, and their importance judgments were elicited using the AHP method. Note that the results obtained from the individual were not updated to reflect RENMOD's final attribute structure. Instead, the old attribute structure was retained because the simulation for the model robustness, in Appendix C, was conducted using weights for the old attributes. Assessment of the weighting schemes would not be affected by the subsequent revision of the attribute structure.

Knowledgeable Individual

The "knowledgeable individual" knew the details of the simulated facility renewal issue, functional condition evaluation, RENMOD, and the weighting schemes. This person was asked to assess the importance of all functional condition attributes using three different weighting schemes. At least 1 day passed between the use of each method so the individual would not remember earlier judgments.

The results are summarized in Table B1.

There are minor discrepancies among the weights assigned by the same person using different methods. To check whether such discrepancies can have significant impact on the final result, a robustness analysis was conducted (see Appendix C).

Table B1

Results of Different Weighting Schemes Used by the Same Individual

	Ratio Method	*AHP Method*	*SWING Method*	*Point Allocation Method*
Functional Condition	Weight	Weight	Weight	Weight
Building Layout Suitability	0.256	0.268	0.346	0.3
Health and Safety	0.128	0.188	0.173	0.12
Grounds	0.064	0.046	0.052	0.07
Sound and Visual Environment	0.096	0.081	0.069	0.08
Electrical	0.096	0.089	0.069	0.08
Water/Plumbing	0.077	0.058	0.052	0.07
HVAC	0.096	0.101	0.069	0.08
Built-In-Equipment	0.006	0.009	0.003	0.01
Security	0.064	0.045	0.042	0.06
Communications	0.064	0.08	0.069	0.06
Enviromental Impact	0.032	0.016	0.028	0.05
Aesthetics/Image	0.019	0.02	0.028	0.02
Building Layout Suitability	**Weight**	**Weight**	**Weight**	**Weight**
Functional Spaces (Quantitative)	0.221	0.449	0.408	0.4
Functional Space Layout Suitability	0.176	0.191	0.204	0.2
Supporting Spaces	0.074	0.154	0.204	0.2
Ceiling Height	0.221	0.02	0.02	0.02
Access to Material and Equipment	0.074	0.084	0.082	0.1
Handicap Access	0.015	0.082	0.061	0.05
Floors	0.221	0.02	0.02	0.03
Functional Spaces (Quantitative)	**Weight**	**Weight**	**Weight**	**Weight**
Availability of Functional Spaces	0.5	0.5	0.5	0.5
Proportions and Dimensions	0.5	0.5	0.5	0.5
Functional Space Layout Suitability	**Weight**	**Weight**	**Weight**	**Weight**
Shape Of Functional Spaces	0.8	0.875	0.625	0.7
Functional Adjacencies	0.2	0.125	0.375	0.3
Supporting Spaces	**Weight**	**Weight**	**Weight**	**Weight**
Availability of Supporting Spaces	0.833	0.9	0.667	0.7
Layout of Supporting Spaces	0.167	0.1	0.333	0.3

Table B1 (continued)

Access to Material and Equipment	Weight	Weight	Weight	Weight
Width and Height of Doors	0.5	0.167	0.333	0.5
Circulation (corridor, width etc.)	0.5	0.833	0.667	0.5
	Ratio Method	*AHP Method*	*SWING Method*	*Point Allocation Method*
Floors	**Weight**	**Weight**	**Weight**	**Weight**
Floor Loads	0.889	0.125	0.231	0.3
Floor Finishes	0.111	0.875	0.769	0.7
Health and Safety	**Weight**	**Weight**	**Weight**	**Weight**
Fire Safety	0.25	0.25	0.303	0.25
Health Risks	0.25	0.25	0.303	0.25
Operational Safety	0.25	0.25	0.091	0.25
Structural Safety	0.25	0.25	0.303	0.25
Grounds	**Weight**	**Weight**	**Weight**	**Weight**
Parking	0.353	0.231	0.333	0.3
Vehicular Access	0.588	0.231	0.476	0.5
Landscaping	0.059	0.231	0.19	0.2
Sound and Visual Environment	**Weight**	**Weight**	**Weight**	**Weight**
Acoustics	0.667	0.75	0.588	0.7
Visual Environment and Glare	0.333	0.25	0.412	0.3
Electrical	**Weight**	**Weight**	**Weight**	**Weight**
Building Power Supply	0.4	0.462	0.435	0.4
Power Distribution	0.4	0.462	0.348	0.4
Adequacy of Electrical Fixtures	0.2	0.077	0.217	0.2
Water/Plumbing	**Weight**	**Weight**	**Weight**	**Weight**
Water Supply	0.667	0.875	0.625	0.7
Plumbing System	0.333	0.125	0.375	0.3

Table B1 (continued)

HVAC Suitability	Weight	Weight	Weight	Weight
Temperature and Humidity	0.5	0.5	0.5	0.5
Ventilation	0.5	0.5	0.5	0.5

Aesthetics/Image	Weight	Weight	Weight	Weight
Exterior Appearance	0.333	0.429	0.37	0.33
Appearance of Public Spaces	0.333	0.429	0.37	0.34
Appearance of Interior Spaces	0.333	0.143	0.259	0.33

Six Planners

Six facility planners from different installations tested RENMOD, and selected the AHP method as the most effective weighting scheme. The results of the planners' judgments are given in Tables B2 and B3, for administrative and general-purpose facilities, respectively.

There are substantial differences between the weights assigned by the different planners. These differences may be attributed to the following factors:

1. The planners received only a brief introduction (about 30 minutes) to AHP before they started using it. They might have made mistakes through inexperience. The high inconsistency ratios support this possibility.

2. The planners, coming from different backgrounds and installations, may have been influenced by their immediate facility planning problems. This phenomenon, called *salience effect*, causes an individual to perceive a currently pressing issue as more important than it is in general (Taylor 1982).

3. Planners simply disagree on the importance of certain attributes.

Through a systematic analysis and some carefully designed communication between the analyst and planners, these discrepancies may be identified and minimized.

Table B2

Results of Weighting Exercise for Administrative Facility by Six Planners Using AHP

ADMIN Facility						
Functional Condition	**A**	**B**	**C**	**D**	**E**	**F**
Building Layout Suitability	0.08	0.117	0.093	0.03	0.046	0.106
Health and Safety	0.127	0.248	0.244	0.25	0.072	0.236
Grounds	0.064	0.012	0.02	0.016	0.041	0.013
Sound and Visual Environment	0.12	0.035	0.021	0.039	0.03	0.04
Electrical	0.129	0.116	0.12	0.069	0.096	0.054
Water/Plumbing	0.099	0.054	0.112	0.069	0.096	0.041
HVAC	0.085	0.054	0.167	0.069	0.114	0.084
Built-In-Equipment	0.037	0.012	0.032	0.025	0.021	0.05
Security	0.093	0.038	0.03	0.098	0.062	0.048
Communications	0.06	0:091	0.119	0.069	0.089	0.062
Enviromental Impact	0.086	0.201	0.024	0.255	0.316	0.249
Aesthetics/Image	0.02	0.023	0.018	0.012	0.017	0.018
Building Layout Suitability	**A**	**B**	**C**	**D**	**E**	**F**
Functional Spaces (Quantitative)	0.114	0.222	0.242	0.186	0.088	0.148
Functional Space Layout Suitability	0.158	0.118	0.242	0.113	0.116	0.165
Supporting Spaces	0.178	0.022	0.086	0.066	0.044	0.113
Ceiling Height	0.157	0.027	0.027	0.042	0.068	0.053
Access to Material and Equipment	0.12	0.071	0.116	0.116	0.15	0.056
Handicap Access	0.243	0.352	0.26	0.452	0.292	0.431
Floors	0.029	0.188	0.027	0.026	0.242	0.034
Functional Spaces (Quantitative)	**A**	**B**	**C**	**D**	**E**	**F**
Availability of Functional Spaces	0.5	0.875	0.75	0.9	0.833	0.167
Proportions and Dimensions	0.5	0.125	0.25	0.1	0.167	0.833
Functional Space Layout Suitability	**A**	**B**	**C**	**D**	**E**	**F**
Shape Of Functional Spaces	0.75	0.833	0.25	0.75	0.25	0.167
Functional Adjacencies	0.25	0.167	0.75	0.25	0.75	0.833
Supporting Spaces	**A**	**B**	**C**	**D**	**E**	**F**
Availability of Supporting Spaces	0.5	0.875	0.833	0.833	0.875	0.75
Layout of Supporting Spaces	0.5	0.125	0.167	0.167	0.125	0.25

Table B2 (continued)

ADMIN Facility						
Access to Material and Equipment	**A**	**B**	**C**	**D**	**E**	**F**
Width and Height of Doors	0.5	0.25	0.5	0.167	0.5	0.5
Circulation (corridor, width etc.)	0.5	0.75	0.5	0.833	0.5	0.5
Floors	**A**	**B**	**C**	**D**	**E**	**F**
Floor Loads	0.833	0.833	0.9	0.875	0.888	0.833
Floor Finishes	0.167	0.167	0.1	0.125	0.113	0.167
Health and Safety	**A**	**B**	**C**	**D**	**E**	**F**
Fire Safety	0.224	0.165	0.418	0.223	0.125	0.3
Health Risks	0.161	0.403	0.217	0.223	0.125	0.3
Operational Safety	0.13	0.335	0.081	0.509	0.125	0.3
Structural Safety	0.484	0.098	0.283	0.045	0.625	0.1
Grounds	**A**	**B**	**C**	**D**	**E**	**F**
Parking	0.49	0.081	0.243	0.303	0.455	0.455
Vehicular Access	0.451	0.638	0.669	0.607	0.455	0.455
Landscaping	0.059	0.281	0.088	0.09	0.091	0.091
Sound and Visual Environment	**A**	**B**	**C**	**D**	**E**	**F**
Acoustics	0.5	0.833	0.875	0.75	0.75	0.5
Visual Environment and Glare	0.5	0.167	0.125	0.25	0.25	0.5
Electrical	**A**	**B**	**C**	**D**	**E**	**F**
Building Power Supply	0.526	0.143	0.429	0.658	0.253	0.253
Power Distribution	0.304	0.429	0.429	0.253	0.658	0.658
Adequacy of Electrical Fixtures	0.17	0.429	0.143	0.089	0.089	0.089

Table B2 (continued)

ADMIN Facility						
Water/Plumbing	**A**	**B**	**C**	**D**	**E**	**F**
Water Supply	0.5	0.5	0.75	0.875	0.75	0.75
Plumbing System	0.5	0.5	0.25	0.125	0.25	0.25
HVAC Suitability	**A**	**B**	**C**	**D**	**E**	**F**
Temperature and Humidity	0.5	0.167	0.5	0.75	0.5	0.75
Ventilation	0.5	0.833	0.5	0.25	0.5	0.25
Aesthetics/Image	**A**	**B**	**C**	**D**	**E**	**F**
Exterior Appearance	0.321	0.106	0.429	0.12	0.14	0.455
Appearance of Public Spaces	0.225	0.26	0.429	0.549	0.574	0.455
Appearance of Interior Spaces	0.454	0.633	0.143	0.331	0.286	0.091

Table B3

Results of Weighting Exercise for General-Purpose Facility by Six Planners Using AHP

WAREHOUSE Facility						
Functional Condition	**A**	**B**	**C**	**D**	**E**	**F**
Building Layout Suitability	0.17	0.133	0.116	no entry	0.159	0.103
Health and Safety	0.255	0.203	0.283	no entry	0.093	0.269
Grounds	0.012	0.01	0.04	no entry	0.027	0.013
Sound and Visual Environment	0.077	0.037	0.012	no entry	0.024	0.072
Electrical	0.095	0.071	0.088	no entry	0.091	0.045
Water/Plumbing	0.097	0.045	0.076	no entry	0.061	0.045
HVAC	0.095	0.073	0.017	no entry	0.067	0.045
Built-In-Equipment	0.039	0.019	0.063	no entry	0.033	0.092
Security	0.033	0.104	0.125	no entry	0.091	0.044
Communications	0.055	0.058	0.041	no entry	0.06	0.036
Enviromental Impact	0.058	0.233	0.112	no entry	0.274	0.222
Aesthetics/Image	0.014	0.014	0.026	no entry	0.02	0.015

Building Layout Suitability	**A**	**B**	**C**	**D**	**E**	**F**
Functional Spaces (Quantitative)	0.294	no entry	0.173	0.223	0.155	0.14
Functional Space Layout Suitability	0.265	no entry	0.188	0.158	0.24	0.174
Supporting Spaces	0.152	no entry	0.051	0.051	0.097	0.105
Ceiling Height	0.124	no entry	0.198	0.06	0.142	0.038
Access to Material and Equipment	0.081	no entry	0.129	0.129	0.233	0.069
Handicap Access	0.053	no entry	0.038	0.346	0.046	0.451
Floors	0.03	no entry	0.223	0.034	0.087	0.023

Functional Spaces (Quantitative)	**A**	**B**	**C**	**D**	**E**	**F**
Availability of Functional Spaces	0.5	0.833	0.75	0.875	0.25	0.167
Proportions and Dimensions	0.5	0.167	0.25	0.125	0.75	0.833

Functional Space Layout Suitability	**A**	**B**	**C**	**D**	**E**	**F**
Shape Of Functional Spaces	0.75	0.167	0.25	0.875	0.25	0.833
Functional Adjacencies	0.25	0.833	0.75	0.125	0.75	0.167

Supporting Spaces	**A**	**B**	**C**	**D**	**E**	**F**
Availability of Supporting Spaces	0.75	0.833	0.75	0.875	0.5	0.167
Layout of Supporting Spaces	0.25	0.167	0.25	0.125	0.5	0.833

Table B3 (continued)

WAREHOUSE Facility						
Access to Material and Equipment	A	B	C	D	E	F
Width and Height of Doors	0.5	0.5	0.5	0.25	0.5	0.5
Circulation (corridor, width etc.)	0.5	0.5	0.5	0.75	0.5	0.5
Floors	A	B	C	D	E	F
Floor Loads	0.833	0.833	0.75	0.875	0.5	0.833
Floor Finishes	0.167	0.167	0.25	0.125	0.5	0.167
Health and Safety	A	B	C	D	E	F
Fire Safety	0.161	0.159	0.399	0.25	0.25	0.3
Health Risks	0.224	0.21	0.161	0.25	0.25	0.3
Operational Safety	0.13	0.573	0.083	0.25	0.25	0.3
Structural Safety	0.484	0.058	0.357	0.25	0.25	0.1
Grounds	A	B	C	D	E	F
Parking	0.49	0.232	0.302	0.263	0.216	0.216
Vehicular Access	0.451	0.697	0.622	0.685	0.729	0.723
Landscaping	0.059	0.072	0.076	0.052	0.055	0.061
Sound and Visual Environment	A	B	C	D	E	F
Acoustics	0.167	0.833	0.25	0.75	0.5	0.75
Visual Environment and Glare	0.833	0.167	0.75	0.25	0.5	0.25
Electrical	A	B	C	D	E	F
Building Power Supply	0.455	0.09	0.429	0.697	0.26	0.253
Power Distribution	0.455	0.607	0.429	0.232	0.633	0.658
Adequacy of Electrical Fixtures	0.091	0.303	0.143	0.072	0.106	0.089
Water/Plumbing	A	B	C	D	E	F
Water Supply	0.5	0.833	0.75	0.833	0.5	0.75
Plumbing System	0.5	0.167	0.25	0.167	0.5	0.25

Table B3 (continued)

WAREHOUSE Facility						
HVAC Suitability	**A**	**B**	**C**	**D**	**E**	**F**
Temperature and Humidity	0.25	0.75	0.5	0.75	0.25	0.75
Ventilation	0.75	0.25	0.5	0.25	0.75	0.25
Aesthetics/Image	**A**	**B**	**C**	**D**	**E**	**F**
Exterior Appearance	0.225	0.072	0.455	0.14	0.333	0.14
Appearance of Public Spaces	0.454	0.232	0.455	0.574	0.333	0.286
Appearance of Interior Spaces	0.321	0.697	0.091	0.286	0.333	0.574

APPENDIX C: Robustness Analysis of the Weighting Schemes and Model

The proposed model and weighting scheme requires a substantial amount of judgmental input. Therefore, it is important that the model results are not sensitive to the inevitable variances in judgments among individuals, over time, or at different locations.

In Appendix B, weights elicited from a knowledgeable individual using different weighting schemes are shown (Table B1). Minor discrepancies are evident among the weights assigned by the same person using different methods. The effects of such minor discrepancies on the FCI was tested.

Using the Monte Carlo simulation, 100 sets of attribute scores were generated. The following case was simulated: suppose 100 different individuals evaluated the functional condition of a given facility over each attribute given in this report. Assume that each individual can assign a different score to the same attribute. Suppose also that the range of difference can be as large as three points out of eight. In other words:

- Each attribute is assigned a score between 0 (worst possible) and 8 (best possible)

- The score assigned by each individual to each attribute can be any number between 1.5 and 4.5— a random variable uniformly distributed with mean 3 and range 3.

Using the weights given by each method, the overall functional condition of the hypothetical facility is computed. These results are given in Table C1 and are plotted in Figure C1. A visual inspection indicates that the overwhelming majority of the results fall between 2.5 and 3.5, i.e., a range of one point. This is a remarkably robust result.

Table C1

Simulation Results Based on a Knowledgeable Individual's Weights

	Ratio Method	AHP Method	Swing Method	Point Allocation Method		Ratio Method	AHP Method	Swing Method	Point Allocation Method
1	2.68	3.03	3.35	2.79	51	3.2	3.02	2.86	3.62
2	3.44	4.39	2.92	3.11	52	3.58	2.95	3.46	3.27
3	2.96	3.28	3.55	3.69	53	2.55	3.29	3.24	3.69
4	2.7	3.29	3.13	2.88	54	3.19	3.49	2.76	3.34
5	3.56	3.55	3.52	3.15	55	2.31	3.69	3.86	2.62
6	3.78	3.28	2.83	3.81	56	2.84	2.71	2.82	3.64
7	2.94	3.5	2.32	3.02	57	3.52	2.75	3.18	3.22
8	3.54	2.78	4.06	3.53	58	3.09	3.2	2.64	2.97
9	2.87	3.53	3.5	3.1	59	3.48	3.43	3.32	2.99
10	3.42	3.17	3.04	3.67	60	3.86	2.58	2.61	2.9
11	2.99	2.93	3.3	3.23	61	3.18	2.93	3.31	3.41
12	3.25	2.62	3.75	2.69	62	3.44	3.22	3.14	2.93
13	3.55	3.81	3.35	3.46	63	3.38	3.47	3.56	3.22
14	3.72	3.17	2.86	3.04	64	3.06	3.58	3.36	2.88
15	3.34	2.76	2.87	2.68	65	2.7	2.87	3.13	3.68
16	3.41	3.34	2.57	4.11	66	3.07	2.9	3.98	3.25
17	2.93	2.94	3.14	3.15	67	3.19	3.7	3.36	3.43
18	3.14	2.92	3.39	2.94	68	3.1	3.11	3.3	3.9
19	3.39	3.46	2.48	3.13	69	2.59	3.12	3.44	2.87
20	3.4	2.68	3.11	3.1	70	3.31	3.14	3.2	3.72
21	3.33	2.7	2.82	2.91	71	3.02	3.14	2.81	3.21
22	2.97	3.17	3.39	3.25	72	2.76	3.25	3.13	3.27
23	2.48	3.47	3.81	3.06	73	3.92	3.22	3.35	3.12
24	3.3	3.59	4.2	3.59	74	3.39	3.04	2.95	3.22
25	3.32	4.1	3.35	3.12	75	4.16	2.96	2.99	3.33
26	3.51	2.84	3.66	3.29	76	3.74	3.55	3.37	2.53
27	3.42	3.55	2.43	3.82	77	3.44	3.15	3.26	3.91
28	3.71	3.8	3.19	3.28	78	3.5	3.54	3.14	3.28
29	3.18	3.41	3.54	3.12	79	2.91	3.55	3.8	3.37
30	3.59	2.73	3.45	3.17	80	3.01	2.77	3.33	3.19
31	2.94	3.12	3.06	3.92	81	3.82	3.28	3.34	3.64
32	3.06	3.67	2.99	2.96	82	3.17	3.51	3.59	3.7
33	3.23	3.26	[illegible].99	3.46	83	3.21	3.6	3.33	3.26
34	2.93	3.27	[illegible]2	3.06	84	3.81	2.99	3.83	2.99
35	3.46	3.55	3.36	3.16	85	3.14	3.76	3.36	3.17
36	2.68	3.89	3.28	2.24	86	3.12	3.21	3.24	3.41
37	3.28	3.77	3.65	3.51	87	3.41	3.4	3.6	3.19
38	3.1	2.81	3.86	3.8	88	3.55	3.13	2.79	3.17
39	3.73	3.64	2.91	3.97	89	3.32	2.4	2.9	3.41
40	2.95	2.68	2.81	3.36	90	3.15	3.93	3.4	3.96
41	3	3.01	2.96	3.49	91	3.44	3.04	3.29	2.94
42	3.14	2.72	3.19	3.56	92	3.42	2.51	3.49	3.72
43	4.06	3.99	3.37	3.57	93	2.99	2.49	2.75	3.34
44	2.85	3.13	2.9	3.23	94	3.48	3.57	2.85	3.27
45	3.12	3.17	4.04	3.08	95	3.01	2.9	3.7	3.27
46	3.85	2.36	3.34	3.15	96	3.27	3.03	3.78	3.47
47	4.31	3.55	3.83	3.63	97	3.06	3.73	4.09	3.37
48	3.71	3.07	3.6	3.18	98	3.48	2.89	3.44	3.74
49	3.44	3.88	3.04	2.81	99	2.89	2.68	3.73	3.2
50	3.93	1.8	3.39	3.87	100	3.62	3	3.61	3.1

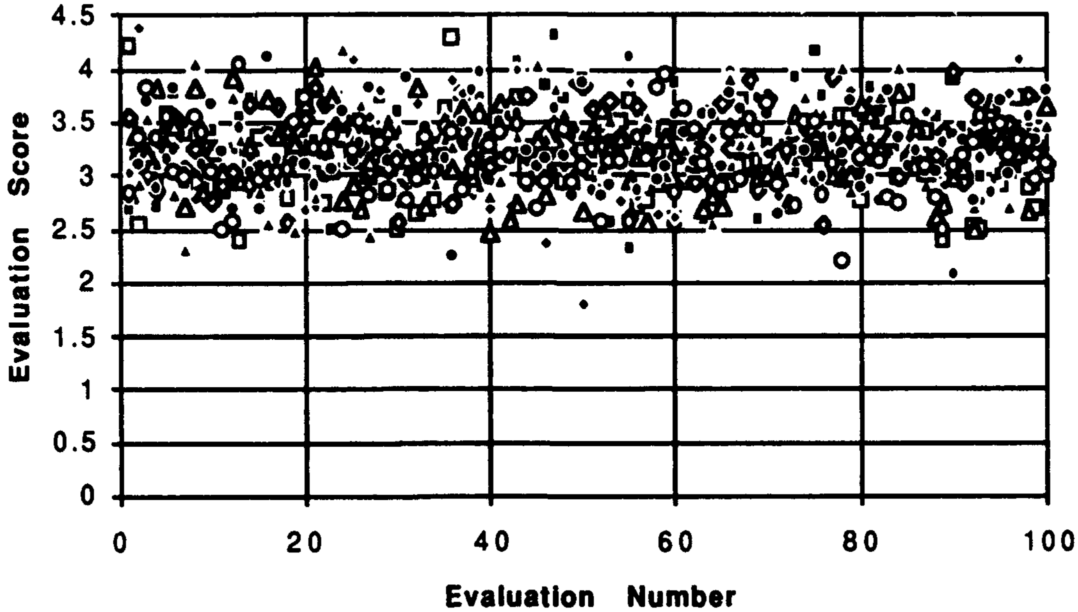

Figure C1. Plot of Simulated FCIs Using a Knowledgeable Individual's Results. Note: Each different shape refers to a different weighting scheme used by KI.

Next, a more realistic case was simulated. Suppose the weights are given. One-hundred inspectors assess the condition of each attribute of a given facility. Suppose the facility is in relatively poor shape, so the scores for each attribute vary uniformly between 0 and 4. Then, the overall FCI given by each inspector is computed. As shown in Figure C2, the resulting functional indices are not widely spread, but are concentrated around 2.00, as expected. The judgmental variances of between 0 and 4 were not passed along to the resulting indices. The great majority of the results fall between a narrow range of 1.82 and 2.20. This is a remarkably robust result for uniform distribution.

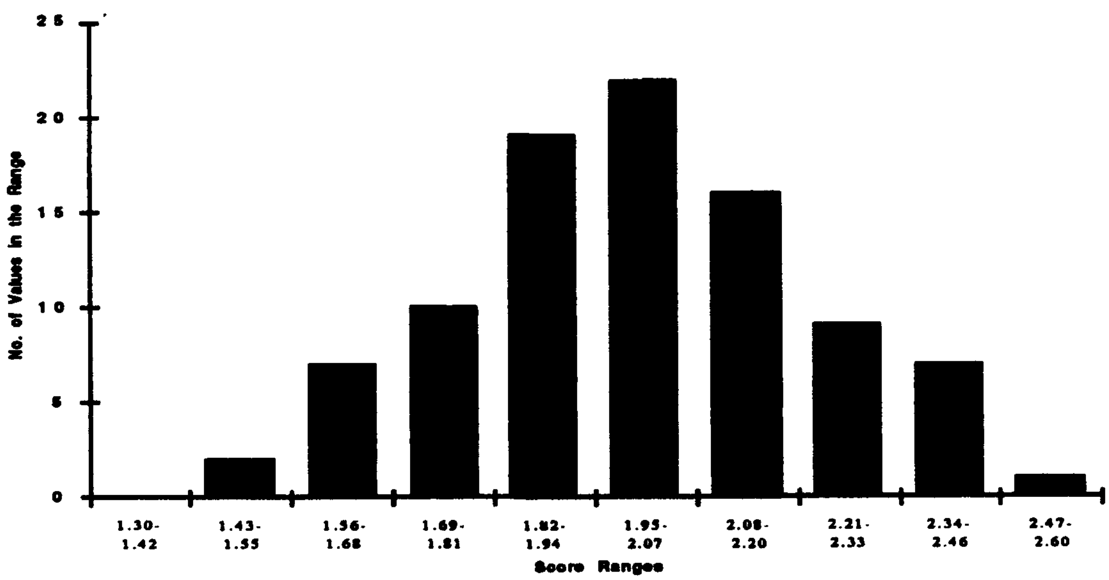

Figure C2. Simulated FCIs Using 100 Hypothetical Inspectors.

APPENDIX D: Condition Evaluation Report

```
                RENOVATION DECISION SUPPORT SESSION REPORT

* Facility type: admin

* Mission type: permanent

* Utilization: overutilized

* Facility type (permanent or temporary): permanent

* Facility condition: 0.783

   -------------------------------------
   Functional Condition: 0.790
   weight: 0.600

      Functional condition recommendation:

         This facility is functionally adequate.
         Functional condition threshold level is 0.69.

   -------------------------------------

     1. Functional spaces suitability: 0.750
        weight: 0.100

        1.1. Functional spaces (quantitative): poor (4.0)
             weight: 0.500
        1.2. Functional space layout: good (8.0)
             weight: 0.500

     2. Supporting spaces suitability: 0.834
        weight: 0.081

        2.1. Supporting spaces (quantitative): good (8.0)
             weight: 0.667
        2.2. Layout of supporting spaces: poor (4.0)
             weight: 0.333

     3. Ceiling height: moderate (6.0)
        weight: 0.021

     4. Access to material and equipment: 0.917
        weight: 0.039

        4.1. Width and height of doors: moderate (6.0)
             weight: 0.333
        4.2. Circulation (corridor width etc.): good (8.0)
             weight: 0.667

     5. Handicap access: good (8.0)
        weight: 0.032

     6. Floors: 1.000
        weight: 0.021

        6.1. Floor loads: good (6.0)
             weight: 0.231
        6.2. Floor finishes: good (8.0)
             weight: 0.769
```

7. Health and safety: 0.890
weight: 0.060

    7.1. Fire safety: excellent (8.0)
    weight: 0.330
    7.2. Health risks (asbestos, fumes, radon, etc.): moderate (4.0)
    weight: 0.330
    7.3. Operational safety: good (6.0)
    weight: 0.340

8. Grounds: 0.840
weight: 0.060

    8.1. Parking: good (6.0)
    weight: 0.333
    8.2. Vehicular access: moderate (4.0)
    weight: 0.476
    8.3. Landscaping: good (6.0)
    weight: 0.190

9. Sound and visual environment: 1.000
weight: 0.060

    9.1. Acoustics: good (6.0)
    weight: 0.588
    9.2. Visual environment and glare: good (6.0)
    weight: 0.412

10. Electrical service: 0.855
weight: 0.060

    10.1. Building power supply: moderate (4.0)
    weight: 0.435
    10.2. Power distribution: good (6.0)
    weight: 0.348
    10.3. Adequacy of fixtures: good (6.0)
    weight: 0.217

11. Water/Plumbing: 0.667
weight: 0.060

    11.1. Water supply: moderate (4.0)
    weight: 0.625
    11.2. Plumbing system: moderate (4.0)
    weight: 0.375

12. HVAC suitability: 0.667
weight: 0.060

    12.1. Temperature and humidity: moderate (4.0)
    weight: 0.500
    12.2. Ventilation: moderate (4.0)
    weight: 0.500

13. Built-In-Equipment: moderate (4.0)
weight: 0.060

14. Security: good (6.0)
weight: 0.060

15. Communications: good (6.0)
weight: 0.060

16. Environmental impact: good (6.0)
weight: 0.060

17. Aesthetics/Image: 0.703
    weight: 0.040

    17.1. Exterior appearance: moderate (4.0)
          weight: 0.370
    17.2. Appearance of public spaces: good (6.0)
          weight: 0.370
    17.3. Appearance of interior spaces: poor (2.0)
          weight: 0.260

18. Location suitability:
    weight:

    18.1. Landuse compatibility:
          weight:
    18.2. Environmental compliance:
          weight:
    18.3. Safety compliance:
          weight:
    18.4. Impact on ACOE:
          weight:
    18.5. Transportation suitability:
          weight:
    18.6. Suitability of utilities:
          weight:
    18.7. Efficiency of operations:
          weight:

Physical condition: 0.773
weight: 0.400

1. Roof: 0.670
   weight: 0.125

2. Flooring: 0.890
   weight: 0.125

3. Exterior closure: 0.900
   weight: 0.125

4. Interior closure: 0.560
   weight: 0.125

5. Structure: 0.780
   weight: 0.125

6. HVAC: 0.880
   weight: 0.125

7. Electrical (physical): 0.700
   weight: 0.125

8. Plumbing (physical): 0.800
   weight: 0.125

ABBREVIATIONS AND ACRONYMS

ACTS	Army Criteria Tracking System
AEI	Architectural and Engineering Instruction
AHP	analytical hierarchy process
AR	Army Regulation
ASTM	American Society for Materials and Testing
BCI	Building Condition Index
DCIS	Design Criteria Information System
DOD	Department of Defense
DR-REAL	Desktop Resource for Real Property
FCI	Functional Condition Index
IFS-M	Integrated Facilities System–Mini/Micro
IPDB	Intelligent Project Development Brochure
M&R	maintenance and repair
MCA	Military Construction, Army
MRPM	Maintenance Resource Prediction Model
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PDB	project development brochure
RPLANS	Real Property Planning and Analysis System
USACE	U.S. Army Corps of Engineers
USACERL	U.S. Army Construction Engineering Research Laboratories
USAREUR	U.S. Army, Europe

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